

# **AN AUTOMATED DYNAMIC SITE LAYOUT PLANNING SYSTEM - A CASE STUDY OF EGYPT**

**Elbadr Mohamed Mohamed Osman Ahmed Elgendi**

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# **AN AUTOMATED DYNAMIC SITE LAYOUT PLANNING SYSTEM - A CASE STUDY OF EGYPT**

**Elbadr Mohamed Mohamed Osman Ahmed Elgendi**

School of the Built Environment  
University of Salford, Salford, UK

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*To Roqaya & Noure*

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## **ABSTRACT**

One of the serious tasks in the construction planning was the site layout planning as it had a considerable effect on construction sites. However, in practice site layout planning was often ignored or overlooked due to its complexity. Project Managers often performed a site layout planning based on experience, ad-hoc rules and first-come-first-serve approach which may lead to inefficient site layouts that had a negative effect on construction projects.

Therefore, the automated systems can be considered as the most effective methods to develop an efficient site layout as they fully covered all concerns that cannot be taken into account by manual methods. Although, a lot of automated site layout planning systems had been developed to support this serious planning task. However, they remained having serious limitations and drawbacks such as a single objective, integrating with regular facilities and site areas only, 2D site layouts representation, inefficient approaches to reflect the dynamic nature of construction sites, ignoring space reuse and facilities relocation, equal area space search, generating static layout, did not cover end users' requirements, highly complex for users, ignoring the user interaction and lacking of flexibility in the system design.

This revealed the need to develop new automated systems to cover the limitations and drawbacks of the existing automated systems and offer the end users' requirements. Furtherer more, the quantitative study of survey returned by twelve participations from the Egyptian sites guided this research to list the end users' requirements. These results led to identifying MATrix LABoratory (MATLAB) and Genetic Algorithm (GA) as the suitable tool and technique to overcome the site layout planning limitations and shortcomings as well as offer the end users' requirements.

Therefore, this research had developed an automated dynamic site layout planning system (ASLS) which had positive impacts on the construction industry in terms of: (1) improving the site layout and space planning (2) maintaining the construction projects cost and time; (3) improving the overall safety of construction sites; and (4) protecting the surrounding environment.

The automated system subjected to a validation process through two construction projects based in Egypt to examine its accuracy and effectiveness. The validation process results proved its accuracy and effectiveness in developing optimal site layouts for construction projects. In addition, an evaluation process was used to examine its functionality, completeness, performance, usability and user acceptance through functional (black-box) test, structural (white-box) test and users' trial. The functional (black-box) and structural (white-box) tests results verified its completeness and performance. The users' trial results indicated its usability in terms of effectiveness, efficiency and satisfaction and revealed that it was acceptable to use and efficient as it saved time.

This research concluded that the developed automated system (ASLS) was effective and outperformed existing automated systems in generating global site layouts while satisfying the layout constraints by offering a number of new capabilities. Furthermore, this research contributed to knowledge by creating an innovative dynamic space search method and formulation of a novel objective function that minimized the harmful effect of construction activity on the surrounding neighboring. Recommendation emerged from the research findings were used to suggest the integrating of the automated system with the Computer Aided Drafting (CAD) and Building Information Modelling (BIM) to facilitate the data exchange and provide the project stakeholder with different scenarios of site layout.

# CHAPTER 1

## INTRODUCTION

### 1.1. INTRODUCTION AND BACKGROUND

The Layout Planning research area is concerned with the allocation of activities to space according to a set of criteria; for example, area requirements partially meet some objectives; they are optimized (usually some measurements of communication costs), and received the attention by researchers during the past three decades. The layout planning problems scale range starts from the assignment of activities to cities, sites, circuit boards, campuses or buildings, to the location of equipment, machine and personnel groups on a single floor space of a building as shown in figure (1.1). A layout planning can be used in the design and allocation of space in a new building or the refurbished and extension of space in an existing building (Isaac, Andayesh, & Sadeghpour, 2012; Liggett, 2000).



Figure (1. 1): City, construction site and circuit board layouts.

In the last decade, construction site layout planning research area, which is a number of smaller chunks of layout planning, has gained a lot of interest as a base of a new method for cost and time reduction as well as improving safety in construction sites (Andayesh & Sadeghpour, 2013). The concept of the construction site layout planning task could be simply summarized as finding the needed facilities with their sizes and

shapes, then locating them with space into the site before the project starts (Said & El-Rayes, 2013). Studies have shown that for every dollar spent on preplanning of large projects, four dollars could be saved in their total cost (Hegazy & Elbeltagi, 1999).

However, this selected space must be located as the optimal space in the construction site for the chosen facilities according to some predefined constraints (such as boundary and overlap constraints) to achieve one or more predefined objectives (such as reduction in project's cost or time and improvement in site safety) (Xu & Li, 2012). Taking into consideration the fact that, the site space in construction sites is regarded as a limited resource (Kumar & Cheng, 2015). In addition, the construction activities need different facilities to be exist on construction sites (such as batch plant, tower crane, material storage areas, working areas). These facilities reach the site at different dates and take spaces on the site for various time periods (Andayesh & Sadeghpour, 2013). Therefore, the site layout planning task is considered as a heavy duty process because it needs a lot of complex information from different sources which vary for each project. Furthermore, there is a huge trade-off between its objectives and it is a difficult step to update (Sadeghpour, 2004; Wong, Fung, & Tam, 2010).

In fact, the site layout will be the state that site personnel will witness for the total duration of the construction time, so the organized and well planned site layout may minimize the waste time and cost (i.e. material handling and relocation), the manufacturing industry studies show that If the facility layout is appropriately planned, the reduction of materials handling costs can reach 20–60% (Lam, Tang, & Lee, 2005). Moreover, the safety of the industry can be maximized. (i.e. decrease or prevent accident, maintaining good employee morale and increase labor productivity). The fatality risk is five times more than that in a manufacturing based industry while the risk of a major injury is two and a half times higher in the construction industry

(Gangoellis, Casals, Forcada, Roca, & Fuertes, 2010; Said & El-Rayes, 2013). Furthermore, protecting the surrounding environment (i.e. hazard and harmful materials' storage should not be adjacent to the neighboring hospitals and schools). In addition to the previously mentioned common engineering objectives, there are other interesting aspects that can also be achieved such as aesthetics and usability qualities of a layout (Lien & Cheng, 2012). Thus, the success of any project undertaken depends on the effective layout planning as it has a significant impact on finances, time, productivity, safety and performance of construction projects (Andayesh & Sadeghpour, 2013; Ning & Lam, 2013).

However, the process of the site layout planning, which is the current practices in most projects, is ignored in the planning phase and is often done in the site by the project manager. This is achieved by the modifications of previous layouts depending mainly on the personal experience, common sense and the famous concept 'what comes first serves first' based on inadequate staff or time and incomplete and ill-structured data (Andayesh & Sadeghpour, 2013; El Ansary & Shalaby, 2014). In addition, the engineering drawings can also be used through some drawing sketches of facilities on a paper, then overlaid them on the site map and moved around until the manager obtains a satisfactory layout. However, they are difficult to update. Templates are also used widely by site managers in practice. Templates are cardboard cutouts representing the facilities that are moved around on the site drawing until a satisfactory layout is obtained (Sadeghpour, 2004).

The repetitive and tedious site layout planning process is difficult and complex combinatorial multi objectives optimization problem for the project managers/engineers to manually handle it properly (Lien & Cheng, 2012; Ning & Lam, 2013). Thus, the effectiveness and quality of the layout are reduced (Sadeghpour,

2004; Sanad, Ammar, & Ibrahim, 2008) which may lead to inefficient layouts that need facilities relocation. Facilities relocation may waste a lot of cost and time especially if it were large or complex facilities (such as batch plant). The emergence of inefficient layout may not be recognized at the beginning of the project, but may in the project late stages (due to the vast and quick changes occurred in construction sites) that a layout might be incompetent of achieving the site requirements at that time (OSMAN, 2002). Therefore, automated systems are essentially required to perform this complex planning task and give the site managers, engineers and planners the capabilities to develop, modify and update an efficient site layout (El Ansary & Shalaby, 2014; Said & El-Rayes, 2013).

Although, the construction site layout planning is recognized as a serious task in construction planning that presents a particularly interesting area of study (Yahya & Saka, 2014), it does not have a complete solution for its problems until now. To date, the construction industry is still struggling to develop integrated systems in which software packages can exchange information and work together to solve the site layout planning problems. This is due to the fact that, the current automated systems still have shortcomings and limitations or not realistic and do not achieve the desired construction industry requirements (Abdel-Fattah, 2013). It will be explained in details later in chapter 2.

Construction sites in the Arab Republic of Egypt follow the same current direction in ignoring the site layout planning by developing it in the construction sites based on the project managers/engineers experience, this may lead to some major problems such as exceeding the planned budget and time as well as safety accidents as will be explained in the next section. A study conducted by Masoud (2010) in Egypt shows that the site layout planning is still ignored and overlooked although 100% of the

study' participants confirm that the site layout planning account effective construction process improvement. However, Masouds' study also demonstrates that 73 % of the participants put a site plan but the mostly is not documented, 9 % of them do not draw up a plan, while 18% draw up a plan according to the size of the project, importance of the project and the movement of equipment and employs in the site.

Furthermore, Masoud (2010) clarifies that the main reason of ignoring the site layout planning in Egypt is the companies in Egypt that have poor construction management and planning experience which lead to their lack of attention to pay expenses on mobilization and site planning. Therefore, Egypt can be considered an excellent example to express the state of site layout planning which needs to improve. Thus, it is the focus of this research.

## **1.2. THE RESEARCH PROBLEM**

The current problem of site layout planning is identified through a personal experience, site visits and surveys (questionnaires) with practitioners in the construction industry in the Arab Republic of Egypt where the researcher comes from. It is evident that, the site layout planning task is always done by the project managers on construction sites manually by planning a single site drawing with the major facilities needed on site during the project duration. They depend on their experience, common sense, first come first serve and examples of previous layouts in determining the location of facilities on site. However, they cannot combine of all the factors that could affect the facilities selection, location and relations. In addition, it is too difficult to maintain and update this plan. Thus, inefficient site layouts may occur, which are considered as the prime cause of work flow inefficiency and can increase the overall project cost as well as exceed project planned duration and unsafe work environment present.



In practice during the site visits it was evident that, the absence of a well-planned site layout may lead to some or all of the following problems:

- Wrongly located project facilities (site offices located too near to noisy or hazard activities such as a batch plant or with insufficient overview of the site, fixed cranes are not capable of reaching all parts of the working area and storage facilities having inefficient passage for loading and unloading or located in an insecure area) these problems affect facilities' performance and may involve relocating them to another location.
- Wrongly located Material stores (positioned over a drainage line or in area that will be excavated or too far from the construction activity) these problems may include the transportation of materials with double or triple times to another location.
- Inadequate space allowed (difficulty on maneuvering and transferring circulation of equipment and raw material) these problems may involve waste of time and cost.
- Negative work flow (site accidents and neighbors' harming with locating hazard materials and storages adjacent to them) these problems may involve nonproductive time and cost.

Although a lot of automated site layout systems had been developed (Khalafallah & El-Rayes, 2011; Andayesh & Sadeghpour, 2013; Said & El-Rayes, 2013; Andayesh & Sadeghpour, 2014; Yahya & Saka, 2014; Huang & Wong, 2015; Kumar & Cheng, 2015), none of these systems has been adopted by the construction industry especially in Egypt. This is due to the shortcomings and limitations of these systems such as a single objective, integrating with regular facilities and site areas only, 2D site layouts

representation, inefficient approaches to reflect the dynamic nature of construction sites, ignoring space reuse and facilities relocation, equal area space search, generating static layout, do not cover end users' requirements, being built on real factors measured from sites, highly complex for users, and lacking of flexibility in the system design. Consequently, they cannot be applied to other cases, but only the case they are designed for. In addition, the previous research work on site layout have mainly ignored the user interaction and concentrated on selecting information from their data base. Therefore, the research gap could be summarized in developing an automated system that offers a reasonable solution for site layout planning problems by covering the shortcoming and limitation of the existing systems and offering the end users' requirements.

This research will cover this gap by developing an automated dynamic site layout planning system that could be used in the construction industry especially in Egypt based on Genetic Algorithms as an optimization engine to generate 4D site layouts (consider time factor). This research will depend on the global construction industry (including Egypt) to define the different factors that are influenced by the site layout planning to explicit the undertaken research problem as it will be discussed in chapter 2. Furthermore, it will utilize construction sites in Egypt as case studies to capture the real site circumstance and end users' requirements to develop, validate and evaluate the proposed automated site layout planning system as it will be demonstrated in chapters 3, 5 and 6. The proposed automated site layout planning system will have the capabilities to cover most of the shortcomings and limitations of the existing automated systems as well as it will offer the end user' requirements captured from Egyptian construction sites.

### **1.3. AIM AND OBJECTIVES**

The aim of this research is to develop an automated dynamic site layout planning system for construction sites, based on Genetic Algorithms (GA) as optimization engine using construction sites in Egypt as a case study. This aim is to be achieved via the following objectives:

- Develop an understanding of site layout planning within the construction industry, explore its current practices and challenges.
- Explore existing automated systems to define their limitations, shortcomings and the successful utilizations that can be incorporated within the proposed automated system.
- Collect and capture the site layout planning circumstance and end users' requirements from real Egyptian construction sites.
- Select a suitable research methodology for developing the proposed automated dynamic site layout planning system.
- Define the structure and characteristics of the proposed automated dynamic site layout planning system.
- Develop, validate and evaluate the automated dynamic site layout planning system and draw a set of recommendations for improving automated site layout planning systems.

### **1.4. METHODOLOGICAL STEPS**

In order to achieve the above mentioned research objectives, this research is formulated into three main stages. Each stage contains the following methodological steps to be undertaken:

1. The pre-development stage:
  - i. A comprehensive literature review is undertaken to:
    - Develop an understanding of the site layout planning in the construction industry, examining its current practices, challenges and limitations.
    - Explore, assess and classify the developed automated systems with the techniques they utilize as well as, define their shortcomings, limitations and barriers.
  - ii. A quantitative study (surveys in terms of questionnaires) used to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real Egyptian construction sites.
  - iii. A detailed analysis for the collected data from the Egyptian construction sites with findings from the literature reviews.
  - iv. Identify the existing research methodologies and techniques in order to design and develop an automated site layout planning system, design science has been identified as an appropriate research methodology to achieve the aim of the research.
2. The development stage:
  - i. Design and develop the proposed automated dynamic site layout planning system.
3. The post-development stage:
  - i. Validate the developed automated dynamic site layout planning system accuracy and effectiveness through a simulation experiment on two construction projects based in Egypt as two case studies.

- ii. Evaluate the developed automated dynamic site layout planning system completeness, performance, usability, functionality and user acceptance through functional (black-box), structural (white-box) tests and users' trial.
- iii. Draw recommendations for improving automated site layout planning systems.

## **1.5. THESIS CONTENT**

This thesis consists of three stages which are divided into seven chapters. A schematic guide to the framework of the research discussed in the thesis is illustrated in figure (1.2). A brief summary of each chapter is presented below:

### **Chapter 1 - INTRODUCTION**

This chapter explains the background of the research, the research problem, the aims and objectives of the research. The work undertaken to achieve the objectives and the guide to the research are also presented.

### **Chapter 2 - CRITERIA AND CONCEPTS FOR SITE LAYOUT PLANNING**

This chapter reviews the literatures on the site layout planning. It covers its definitions, concepts and criteria. The chapter refines the focus of the research by outlining the current state of the site layout planning in construction industry, as well as defines the automation process in site layout planning in detail. A detailed view to the developed automated systems and their techniques, limitations and shortcomings are also presented in this chapter.

### **Chapter 3 - TOOLS AND TECHNIQUES FOR THE PROPOSED AUTOMATED SITE LAYOUT PLANNING SYSTEM**

This chapter presents descriptive analysis of the survey carried out to collect and capture the site layout planning circumstance and end users' requirements from real

Egyptian construction sites. The chapter also introduces the proposed automated site layout planning system tool and technique.

#### Chapter 4 - RESEARCH METHODOLOGY

This chapter presents the research methodology. It discusses the methodological considerations for this research and presents the adopted research methods.

#### Chapter 5 – STRUCTURE AND CHARACTERISTICS OF THE PROPOSED MULTI OBJECTIVE AUTOMATED SITE LAYOUT PLANNING SYSTEM

This chapter introduces the structure and characteristics used to develop the proposed multi objective automated site layout planning system to clarify the information structure of parameters in terms of form, behavior and relation. The chapter also presents the expected impacts of the proposed automated system to enhance the construction sites

#### CHAPTER 6 – AUTOMATED SYSTEM IMPLEMENTATION, VALIDATION AND EVALUATION

This chapter presents the details of the automated dynamic site layout planning system (ASLS) implementation, validation and evaluation processes.

#### CHAPTER 7 - DISCUSSION AND CONCLUSION

This chapter discusses the research, assessing it according to the original objectives. The chapter also presents a summary of the major findings obtained and the conclusions derived from the research. It outlines the contributions to knowledge made by this research. The chapter addresses the limitations of the research and proposes future research opportunities.

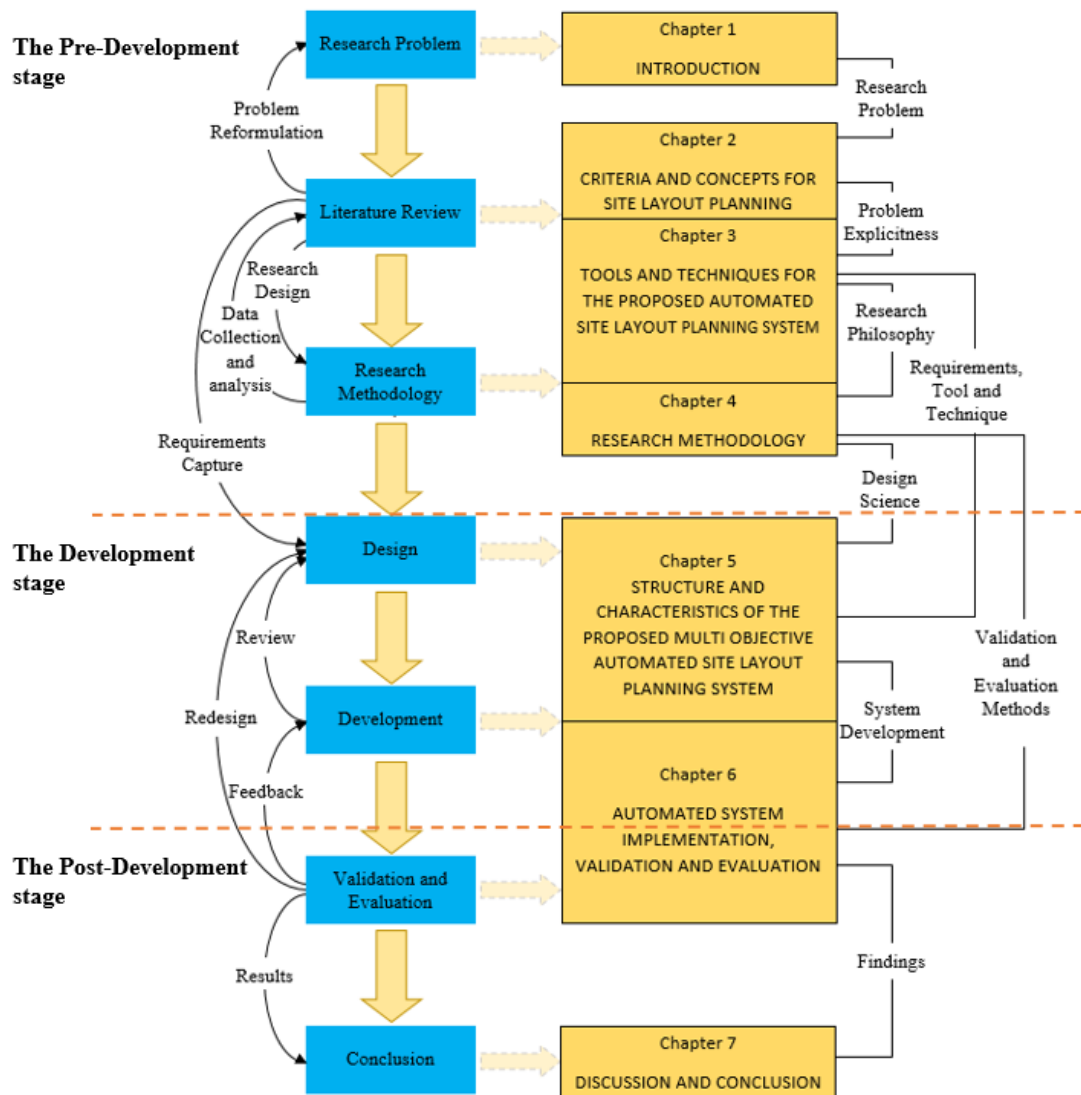


Figure (1. 2): Research framework.

## **CHAPTER 2**

### **CRITERIA AND CONCEPTS FOR SITE LAYOUT PLANNING**

#### **2.1. INTRODUCTION**

The main focus of this chapter is to impart the findings of literature review carried out to examine the state of the art of site layout planning in construction industry and research with the exploration of its factors, challenges and current practices to identify its underpinning criteria and concepts. It begins by briefly exploring the site layout planning definitions which form the basis of the automated site layout planning systems designs and concepts. Three main factors (site space, temporary facilities and permanent facilities) which the site layout planning is concerned with, have been introduced and explained. The chapter will also shed light on the current state of the site layout planning in the construction industry and highlight the positive and negative effects on the construction projects. This chapter then defines the automation process in site layout planning, compares it with traditional methods and identifies the benefits. A detailed view of the developed automated systems and their techniques, barriers, limitations and shortcomings are presented in this chapter to provide successful utilizations that can be incorporated in the implementation in the proposed automated system as demonstrates in the next chapter.

#### **2.2. SITE LAYOUT PLANNING – DEFINITIONS AND CONCEPTS**

This section seeks to define an understanding for the site layout planning and identify the main factors that should be taken into consideration in implementing it. Literature review shows that there are a number of definitions for construction site layout



planning, but the most obvious and generic is defined by Tommelein, Levitt and Hayes-Roth (1992a).

*“The task of site layout consists of identifying the facilities needed to support construction operations, determining their size and shape and positioning them within the boundaries of the available on-site areas. Examples of these facilities include offices and tool trailers, parking lots, warehouses, batch plants, maintenance areas, fabrication yards or buildings, staging areas, and lay-down areas.”*

This definition focuses on identifying the facilities needed to support construction operations as one of the tasks of site layout. On the other hand, Li and love (1998) deal with the site layout planning as finding the location and area for the given temporary facilities.

*“Construction site-level facility layout concerns the allocation of locations and areas for temporary facilities such as warehouses, job offices, various workshops and batch plants.”*

But in (2002) Mawdesley, Al-jibouri and Yang introduce a new definition. Although they keep the basic margins, they consider a new factor beside the space factor which is the time factor for more efficiency in the construction sites.

*“The objective of site layout is to determine what temporary works are required and to position them in space and time throughout the project in such a way as to improve the construction process.”*

However, in the same year (Zouein, Harmanani, & Hajar) develop another definition, but this time they focus on satisfying the constraints between facilities as a factor that governs when allocating the temporary facilities.

*“The site layout planning problem is generally defined as the problem of identifying the number and size of temporary facilities (TFs) to be laid out, identifying constraints between facilities, and determining the relative positions of these facilities that satisfy constraints between and allow them to function efficiently.”*

Furthermore, Sadeghpour, Moselhi and Alkass (2006) give a definition consider the site layout planning as the purpose of multi objectives, minimizing travel distances and maximizing safety.

*“Construction site layout planning determines the optimum location of objects on the construction site, in order to minimize travel distances and maximize safety. Construction site objects include temporary facilities (e.g. batch plant), major equipment (e.g. tower crane), material storage areas (e.g. gravel storage), and working areas (e.g. rebar cutting area), all of which support the construction activities on the site”*

Moreover, Yahya and Saka (2014) are concerned with the tradeoff between the site layout planning objectives and introduce the site layout planning as a process work according to multiple objectives and subject to logical and resources constraints.

*“The basic function of this process is to find the best arrangement of the temporary facilities according to multiple objectives that may conflict with each other and subjected to logical and resources constraints.”*

Based on the aforementioned definitions, there are three main factors that must be taken into consideration. These factors are:

a) Site space

Site space is classified into two different types: available space and unavailable space. The available space is the space that construction site facilities can be positioned. The unavailable space is the space that is not suitable for positing the construction site facilities, it could be the space occupied with the permanent facilities or the space defined as protected zone for the safety considerations. (Easa & Hossain, 2008; Mawdesley et al., 2002).

b) Temporary facilities

Temporary facilities are these facilities that support the construction operation on site but they are not regarded as a part of the proposed building that is required to be built and needed to be located on site. Examples of temporary facilities are material stores, offices, fabrication areas, storage areas, parking and storehouses .... etc. (Sanad et al., 2008).

c) Permanent facilities

Permanent facilities are these facilities that have already fixed location in site. Examples of permanent facilities are proposed structures, trees or existing buildings (Elbeltagi & Hegazy, 1999).

Therefore, based on the above listed definitions and factors this research will define the construction site layout planning task as (finding the optimal layout for construction sites according to facilities duration, constraints and objective's demand by each project). Therefore, this definition considers the site layout planning task as a

search process for the optimal layout for the construction projects based on the needed facilities real duration and specified constraints; however, this layout is generated for the project entire duration or for divided project phases. Furthermore, the definition does not specify a certain objective, but it depends on each project's objectives. This is because each construction project is unique and has different objectives which determine whether the layout is optimal or not. The proposed automated system' design (in chapters 5) is based on this definition, to give the user significant capabilities to control the search process as well as the flexibility to divide the needed facilities according to the way they are involved in the search process, this section will demonstrate in detail later in chapters 5 and 6.

### **2.3. THE IMPORTANCE OF SITE LAYOUT PLANNING IN THE CONSTRUCTION INDUSTRY**

The building and construction industry is an important hub of development axes in the nation's economy for its important role in pushing the economic growth, creating more jobs, moving economic activity in many industries and other activities associated with it. Elnakeb (2010) shows that more than 90 industries and activities are associated with this industry, part of which are connected to pre-construction phase, like studies and real estate consulting offices, engineering offices and marketing companies. While some are linked to the construction phase, such as equipment manufacturing and construction materials industry, some are after the construction phase such as operation and maintenance companies. Therefore, the revival of the construction industry means increased activities in these linked activities and industries, which means that the construction industry is considered one of the important national economy locomotive growth.

The construction industry considers as one of the largest industries in the United States. Historically, make up about 10% of the nation's gross national product and employing around 10 million workers (Nunnaly, 2011). While in the United Kingdom construction industry is one of the pillars of the domestic economy. The construction industry achieved 58 billion GBP in 1998, which account 10% gross domestic product and employs around 1.4 million people (Egan, 1998). In Arab Republic of Egypt, the construction industry is ranked seventh in the order of most important contribution rates of various economic sectors in the gross domestic product during the financial year 2012/2013 at a rate of 4.6% of gross domestic product (General Authority for Investment and Free Zones, 2013). Moreover, it accounts as one of the country's economy fastest-growing sectors with an average growth rate of 20% to 22% annually since the 1980. This is due to the country growth's and population increase which required infrastructure and housing projects (ElSafty, ElSafty, & Malek, 2012). Globally the construction industry accounts as a significant part of national output and productivity. Ruddock (2000) measures construction gross domestic product between 5.58% and 5.95% internationally with a larger percentage in smaller countries.

Although construction industry is considered as an important industry for nation's economy, it has several aspects that need to be improved to avoid its negative influence on the industry. Site layout planning is one of the aspects that needs attention in the construction industry; that is why, it is the focus of this research in order to improve it and promote a solution to reduce its negative impact on the construction industry. Therefore, the rest of this section focuses on the different factors that are influenced by the site layout planning in the construction industry.

An extensive literature review was conducted to demonstrate relevant knowledge and existing research to set a solid understanding for these factors to pursue the proposed

research. The main targets of this literature review were to define all factors that may influenced by the site layout planning in the construction industry such as construction site safety, productivity, cost, time, waste materials and surrounding environments. This literature review was designed to investigate the latest global statistics, researches, publications, studies, regulations and reports in the main domains of this research. Accordingly, this literature review is divided to the following tasks:

1. Investigate previous statistics relevant to construction industry risk, performance and productivity.
2. Explore reports that prepared to identify the construction industry problems and improve its performance such as Egan (1998).
3. Examine available laws, regulations, codes and requirements relevant to construction site safety, performance and productivity.
4. Survey existing publications related to enhance the construction sites performance.
5. Review all available existing research studies in the area of site layout planning.

### **2.3.1. Construction Site Safety**

One of the critical issues in the construction industry is safety. More accidents of greater severity occur in the construction industry than other industrial branches as it equates to a heavy cost to employers and society (Loughborough University & Manchester Centre for Civil and Construction Engineering, 2003). The National Institute for Occupational Safety and Health (NIOSH) (2000) puts construction industry on the top of causing non-fatal injuries at a rate of 9.3 injuries per 100 full-time workers in 1997. Alarming statistics show that the construction industry causes

55,000 fatal injuries each year; which means that one person is killed in a site accident every ten minutes (Murie, 2002).

According to the Bureau of Labor Statistics (BLS) (2004) the construction industry is considered among the top three industries that causes fatal injuries in the United States in 2002 with 12.2 fatalities per 100, 000. Moreover, , in 2010, 4690 workers were killed because of job-related injuries in the United States, 774 (16.5%) of them were from the construction industry (BLS, 2010). The Construction Safety Council (CSC) (2003) indicate that almost around six construction workers died each day in the United States due to construction accidents, illnesses and injuries. Although construction produces 20% of the fatalities; however, it represents only 6% of US workers (ElSafty et al., 2012). Construction industry in Great Britain has been reported as being the primary responsible industry for 31% of deaths occurred at work when compared to other industries in 2002/2003 (Health and Safety Commission (HSC), 2003). Furthermore, in Brazil, the highest incidences of work-related accidents happen due to the construction industry (Fonseca, Lima, & Duarte, 2014).

Regarding the European Union, nearly 13 workers per 100,000 face fatal accidents as against 5 per 100,000 for the all sector average (Eurostat Construction Accident statistics). The Occupational Safety and Health Branch of the Labor Department of Hong Kong (2011) published a survey that indicated that there were 13,658 industrial accidents and 29 industrial fatalities. Most of these accidents occurred within the construction industry. To precise, it is about 3112 (22.8%) of these industrial accidents and 23 (79%) of these fatalities occurred within the construction industry. In Egypt, the construction industry came in sixth place in the recorded rate of work-related injuries distributed according to economic activity (General Authority for Investment and Free Zones, 2013). The real situation for the exact number of injuries in Egypt

seems to be much higher, but there are no precise statistics for these injuries, this is due to the Lack of interest with the safety management, safety plans and recording systems.

Figure (2.1) introduces an example of comparison for the recordable injuries between two construction companies in Egypt and USA after they implement safety programs. Although this figure shows that there is a reduction in the incidence rate of recordable injuries in the construction worksite over five years' period, yet the Egyptian construction company records higher number of injuries than the US Company (ElSafty et al., 2012). This demonstrates that there are attempts being made by construction companies in different countries to reduce injuries that occur on construction sites such as the application of safety programs and prevention methods, but these attempts still need more studies and improvement, particularly in developing countries such as Egypt.

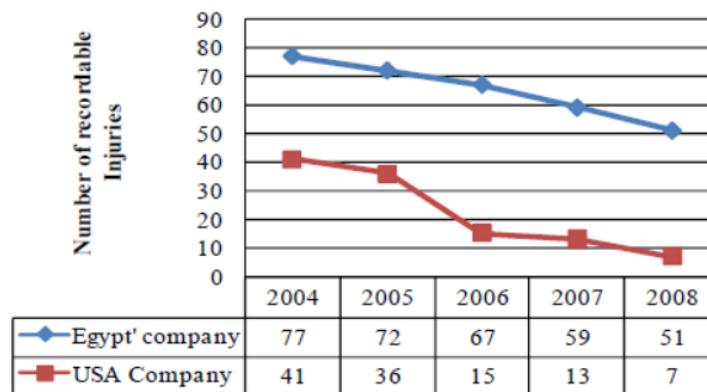


Figure (2. 1): Recordable injuries in the Egyptian and the US construction companies (ElSafty et al., 2012).

Construction workers faced some alerting dangers as the construction work site is usually an unorganized place with high activities. There is a close relation between the accident rates and the level of activity within the industry, meaning that when work



load is high, safety tends to receive less attention. Furthermore, construction sites are filled up with a lot of construction hazards that can lead to serious injury or death. these hazards may include falls, extreme heights, falling from rooftops, machinery failure, unguarded machinery, being struck by heavy construction equipment, electrocutions, silica dust, asbestos, lead, welding emissions, accidents, structure collapses, roofing and pavement tar, engine exhaust fumes, and other hazards (LU & UMIST, 2003).

Abdel Hamid & Everett (2000) reveal that the special nature of the construction industry has to do with primary causes of accidents, as well as, human behavior, difficult work site conditions, and poor work site management which leads to unsafe work methods, equipment and procedure. A research at University College London (UCL) suggests that poor site logistics result in the existence of 20 percent of reported construction accidents (Egan, 1998). A Study by Loughborough University and UMIST in 2003 found that the site layout problems and space availability, resulted in half (49%) of the accident studies (LU & UMIST, 2003).

Moreover, according to the Occupational Safety and Health Administration (OSHA) preplanning of overhead hoisting operations is required in order to make sure that no employee has to work under a suspended load (OSHA, 2003c). OSHA also stresses the importance of suitable storage and appropriate separation of hazardous material in order to reduce the risk of accidents on site (OSHA, 2003c, 2004a).

Based on the above statics, finding and standards, there are many reasons for the site accidents but the site layout problems account as one of the main causes of accidents in a manner directly or indirectly, by creating conditions for the occurrence of accidents (such as difficulty in communication and coordination while safety depends

on them). It is undoubtedly important to improve site layout planning tasks and to give due attention to developing new skills for the prevention methods. The Occupational Safety and Health Act of (1970) defines occupational safety and health standard as, “A standard which requires conditions, or the adoption or use of one or more practices, means, methods, operations, or processes, reasonably necessary or appropriate to provide safe or healthful employment and places of employment”. Thus a step change is required with the practices and methods of site layout planning tasks in construction sites; in addition, it must be a proactive task rather than a reactive task.

### **2.3.2. Construction Site Productivity**

Construction sites productivity is strongly linked to the site safety and site layout condition, because an unhealthy worker or risky work environment, correlates to low company productivity, lost wages for employees (ElSafty et al., 2012). Elbeltagi, Hegazy, and Eldosouky (2004) find that the layout of construction sites is crucial to the site productivity. In current site layout planning practice, site facilities are often positioned in the available location on a first-come first-served basis, but This can lead to the reduction of the safety and productivity rates of construction sites (Andayesh & Sadeghpour, 2013).

The National Safety Council (NCS) presents the magnificent advantages of safety to employers which correlates to the higher profitability to their businesses, minimizing accidents rates and maintaining high productivity. Low productivity is reduced by inefficient space planning and conflicts between subcontractors (Tawfik & Fernando, 2001). Trigunarsyah (2004) shows the analyzing of site layout, access and temporary facilities as the most common activity performed by contractors in Indonesia to improve laborers' productivity.

Improving the labor productivity can be achieved by arranging a safer and a well-planned construction site which leads to the raise of labor morale, spirits, and confidence as well as conflicts reduction. Thus, efficient site layout is expected to contribute in the enhancement of the overall productivity of construction crews on site.

### **2.3.3. Construction Site Cost and Time**

Construction site layout planning is important to any successful project and has a significant impact on both cost and time (Li, Shen, Xu, & Lev, 2015). Planners still carry out the placement of the temporary facilities on site, a key site layout planning task, depending only on their experience and intuition. This usually results in the increase of transportation costs, loss of time, and inefficient use of resources (Tawfik & Fernando, 2001). It is very important to realize that there are certain consequences happen when conflicts occur and relocation of a temporary facility is required. There are losses not only in the cost of relocating the facility, but also in time due to waiting, job interference, labor morale and work discontinuity (Cheng & O'Connor, 1994).

This greatly affects the ease of receiving deliveries and the need for double or triple handling of materials can be of a subsequent need (LU & UMIST, 2003). According to the studies in the manufacturing industry If the facility layout is appropriately planned, the reduction of materials handling costs can reach 20–60% (Lam et al., 2005). Improper planning can result in requiring unnecessary facility relocations in each construction stage, leading to a higher construction cost and longer construction time due to the need to dismantle and erect site facilities (Huang & Wong, 2015).

Inefficient site layout planning can result in another problem which is the difficult communication due to the physical distance among groups of co-workers. Poor communication among work teams can cause some accidents, loss of time and cost

and work discontinuity, because of the physical distance between work colleagues or the high levels of noisy backgrounds they work in (LU & UMIST, 2003). Thus, more practices are needed to improve the site layout planning in order to develop an efficient site layout that helps in reducing the loss of cost and time in site.

#### **2.3.4. Construction Site Waste Materials**

The site layout planning has a direct effect on the waste of materials in construction site, this is due to accommodating the temporary facilities on site by planners based only on their experience. This usually results in inefficient site layouts which have inappropriate locations for the materials storages need to double or triple handling for receiving deliveries or transport it to the work places, which lead to a lot of waste in construction materials. Previous studies in the USA, shows that rework can take up to 30% of construction, while labor can be used at only 40-60% of potential efficiency, accidents can reach for 3-6% of total project costs, and materials can be wasted by at least 10% (Egan, 1998). So developing an efficient site layout could save the waste materials in construction sites.

#### **2.3.5. Construction Site Surrounding Environment**

In addition to the previously mentioned site layout planning effects on construction sites, the site layout planning can contribute to enhancing another aspect which is the priceless aspect. This aspect is protecting the surrounding environment which must be considered in preparing any site layout because it is the construction industry's duty towards the environment and community. For instance, one or more boundaries with schools, hospitals or other environmentally sensitive zones in some cases may be shared with the construction site. In such situations, it must be stressed that the harmful effects because of site activities are within acceptable boundaries. Therefore, noisy

facilities, pollution and vibration (such as batch plant, hazard materials' storage and welding workshop) would have to be placed at a sufficient distance from these zones (Kumar & Cheng, 2015). Thus the site layout planning future studies must account for the protection of the surrounding environment as a main objective as other knowing objectives.

At the end of this section, the importance of the site layout planning task is proved and an efficient site layout can have a considerable effect on the safety, productivity, cost, time, waste materials and surrounding environment on construction sites. Thus attention must be given to site layout planning task regarding the development of its method of implementation in construction sites. Therefore, the current implementation method for executing the site layout planning will be clarified in the next section with its disadvantages, the development required to reduce negative effects as mentioned before, and the achievement of the optimal targets that assists in the success of construction sites.

## **2.4. AUTOMATION IN SITE LAYOUT PLANNING**

Site layout planning is often done on site by the project manager/planner depends mainly on the personal experience, common sense and the famous concept 'what comes first serves first' (El Ansary & Shalaby, 2014). Although construction method, safety, and convenience to the construction operations could be considered by experienced site managers/planners, however work flows, productivity, environmental concern or costs caused by the transportation of materials and equipment cannot be fully taken into consideration by their pure experience (Lam, Ning, & Lam, 2009). These current practices which are used in developing site layouts may lead to inefficient site layouts with a lot of negative effects on construction sites as discussed in the previous section.

From among the most challenging tasks of the construction planning process is site layout planning in terms of organizing the site layout to facilitate construction activities and it involves various steps of human interpretation and usage of data and knowledge (Tawfik & Fernando, 2001). In addition, the site layout planning task is considered as a heavy duty process because it needs a lot of complex information from different sources which vary for each project. Furthermore, there is a huge trade-off between its objectives and it is a difficult step to update (Sadeghpour, 2004; Wong et al., 2010).

Due to the complexity especially in large-scale projects and a large number of factors involved in site planning, automated systems by computers were identified as an efficient tool to help manager/planner with the layout in industrial plants as early as the 1960s. Several attempts have been made to automate the process of site planning and implement automated systems over the last few decades (Andayesh & Sadeghpour, 2014). These automated systems mimic what people do base on artificial intelligent to develop a site layout on the same way like project manager/planner or other better way. Develop such system is meaningful because it has the ability to categorize the crucial factors, identify the problem, analyze the interaction between factors, and comprehend alternative solutions (Tommelein, 1992).

Although a lot of automated site layout systems had been developed and succeeded in generating optimal or near optimal site layouts, a complete automated system for planning the site layout has never been provided; as a result, previous researches' outputs have not been adopted by the industry (Abdel-Fattah, 2013). This is due to the shortcomings and limitations of these automated systems mentioned before in section (1.3). The research aims to develop an automated site layout planning system that will cover most of the shortcomings and limitations of previous systems, so it could be

used in the construction industry especially in Egypt. The next section will introduce a detailed view to the developed automated systems and their technologies, approaches, limitations and shortcomings.

## **2.5. CURRENT STATE OF AUTOMATED SYSTEMS IN THE CONSTRUCTION SITE LAYOUT PLANNING**

There is a long history of research into automated systems in the construction site layout planning. Amongst the first efforts were those utilizing mathematical optimizations and gradually moved towards heuristic automated systems. The main reason for this tendency – apart from the excitement of exercising heuristics – was that only a few of these mathematical automated systems seemed to be successful and even then, these automated systems worked only for the specific case utilized in the system design and cannot be adopted in other projects (Sadeghpour et al., 2006; Tommelein, 1992). First attempts of using the mathematical techniques were in developing facility layouts in industrial engineering by Operations Research systems (Easa & Hossain, 2008). Later, interest leaned towards heuristic procedures.

The heuristics automated systems for site layout problems consist of knowledge prescribing the order of facility selection and meeting the constraints while locating them on site. Due to the combinatorial nature of the site layout planning problems and the large number of factors involved in it the heuristics techniques advised to be a suitable practical solution (Sadeghpour et al., 2006). In addition, a construction site layout is a dynamic problem due to the constantly changing nature of the project (Mawdesley et al., 2002). So, the heuristics techniques advised to be a suitable practical solution.

The rest of this section describes a number of existing automated systems including the advantages and disadvantages of each. This description focuses on modeling issues

including problem structure and representation, the procedure of locating facilities on site, the constraints considered in locating facilities on a construction site and the achieved objective. For convenience in the discussion and comparison, these automated systems are classified based on the techniques or the algorithm they are built on, albeit there are some automated systems that fall in the overlap areas and they will also be mentioned.

## 1. OPERATIONS RESEARCH

The Operation Research (OR) techniques are introduced in industrial engineering before used in construction industry. Operation research techniques are used in industrial engineering to find optimum layout for departments on a manufacturing site. Operation research systems present the behavior of systems via numerical equations and constraints (Tommelein, Castillo, & Zouein, 1992).

CORELAP (Lee & Moore, 1967; Moore, 1971) is one of the first attempts to develop an automated system for site layout planning. The system is designed to locate a set of predetermined departments on an industrial site and calculate a score for the proposed layouts against an objective function. In this system, the objective function expresses the distance between pairs of departments and their respective closeness weight. The system is designed to work interactively with the planner and takes the flow of material, activity relationship (closeness weight) and space needed for each department as input. In locating facilities, CORELAP ranks them in a descending order of closeness relationship. The system then suggests a layout by applying operation research techniques to find a location for each facility and calculating the respective score for the layout.



While this system has a distinctive feature that the user can adjust in the proposed location as needed, the system updates the design score according to the new locations. It demands a large amount of data to run and the locating constraints are limited to minimizing distance (Tommelein et al., 1992). This makes such system so far useful only as far as distance is concerned, whereas in real practice the quality of a proposed layout is judged by a multitude of criteria.

## 2. GENETIC ALGORITHMS

Genetic or evolutionary algorithms are considered as search algorithms which are based on the mechanics of natural selection. They form a search algorithm with some of the creative flair of human search by combining survival of the fittest among string structures after randomized information exchange. A new set of artificial creatures (strings) is created, in every generation, exploiting bits and pieces of the fittest of the old; an occasional new part is tried for good measure. Randomized, genetic algorithms are not simply random walk; however, they efficiently use historical information to study on new search points with expected improved performance (Goldberg, 1989). The application of genetic algorithms to construction site layout is less than a decade old. The first attempt to utilize genetic algorithms for construction site layout is conducted by Philip, Mahadevan, and Varghese (1997).

EvoSite (Elbeltagi & Hegazy, 1999, 2003; Hegazy & Elbeltagi, 1999, 2000) is a site layout automated system based on genetic algorithm that demonstrates more flexibility in representing the shape of facilities and site boundary other than earliest systems. EvoSite is a simplified site layout automated system implemented on the grid structure of a spreadsheet. The site boundary is generated following the grid of the spreadsheet, and hence non-rectangular shapes can be defined while the size of the

grid is selected as a function of the facilities' size. To better represent oblique lines, the system is later adapted to allow the use of different orientations for the grid, selected based on the orientation of the majority of facilities (Elbeltagi & Hegazy, 2003). However, when representing curved lines, the grid is not a fine solution.

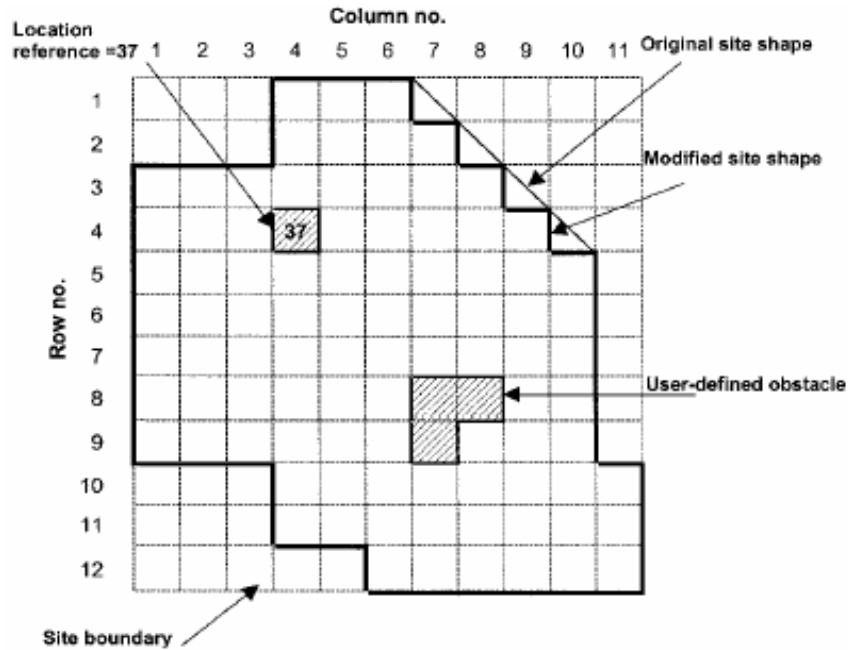


Figure (2. 2): Site and facility representation in the EvoSite system (Hegazy & Elbeltagi, 1999).

In an earlier version of EvoSite (Hegazy & Elbeltagi, 1999), the size of the site grid is calculated according to the greatest common divisor (g.c.d.) of all facility sizes. In this way, facilities are represented as a number of site grids (Figure 2.2). Later in (2000), Hegazy and Elbeltagi change the grid size to be equal to the area of the largest facility with each facility occupying one grid. Consequently, unrealistic problem occurs with this version in the representation of areas of smaller facilities, where a larger site area is considered occupied when only a small part of the grid is actually in use.

Another level of extension is also offered by EvoSite in (2000) by Hegazy and Elbeltagi. It is the definition of three categories for objects on site: facilities, which

are to be located in available cells; fixed facilities that have user defined fixed locations on site; and obstacles that represent non-allocable areas on site. A numerical proximity weight is used to represent the closeness relationship, referred to as a qualitative method. The closeness relationship is calculated based on a quantitative value such as transportation cost per unit of time or the amount of transferred material on site. Six closeness relationships between pairs of facilities (absolutely necessary, especially important, important, ordinary closeness, unimportant and undesirable) are considered and set prior to the optimization (Hegazy & Elbeltagi, 2000). The user can assign desired values to each category, as well as the number of offspring generations, after which the improvement process stops.

Once the layout is designed, it can be used as a template to study the effect of relocating facilities on the objective function. Each time a facility is relocated, the total travel distance is calculated.

A subsequent study by Elbeltagi, Hegazy, Hosny and Eldosouky (2001) adds dynamic capabilities to EvoSite by considering construction schedules in creating site layouts. The automated system in this study creates several layouts for user-defined time intervals. At each time interval, the system calculates new space requirements and generates a layout. In generating new layouts, the automated system considers reusing the space previously occupied by facilities that are no longer needed on site. In addition, it uses parts of constructed space in order to position temporary facilities. Nevertheless, of all capabilities and updates introduced in the different version of EvoSite, it is still single objective automated site layout planning systems that minimizes total travel distance.

Similar to EvoSite, Mawdesley et al., (2002) have developed a dynamic automated system that divides the site area into grids. The shape of facilities in this automated system follows the grid: permanent facilities are represented by a number of grid cells, and temporary facilities are assumed to occupy one grid. In this automated system, other constraints in its objective function encode. The fitness function of the GA is formulated as a summation of material transportation cost, facilities setup cost, facilities removal cost, and personnel visit cost. For each site grid, the cost is calculated based on setup, removal, and travel costs. Some layout constraints are implied by means of these three cost types. For example, in order to deter the consideration of an unavailable site area, an arbitrarily high setup cost is assigned to the corresponding grid cells. Based on the cost distribution on the grid cells, a least cost route between facilities is used as a criterion for facility layout (Figure 2.3). Although the fitness function in this automated system seems to be more comprehensive, it is like EvoSite, it minimizes the cost and imposes rigidity on the shape of the facilities.

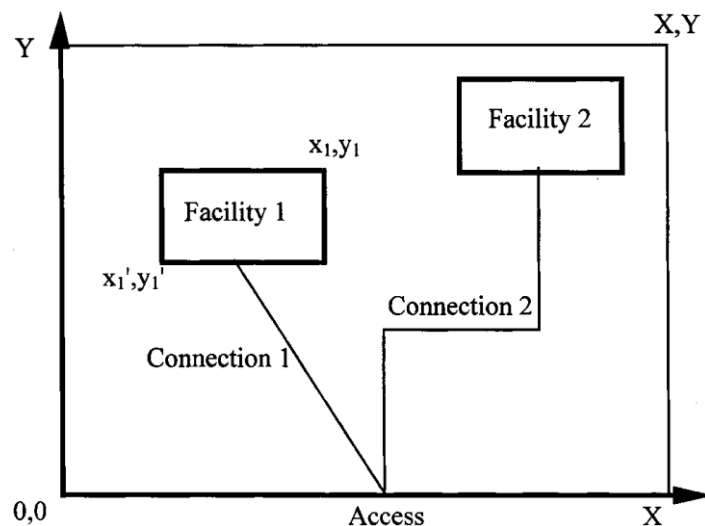


Figure (2. 3): Site and facility representation (Mawdesley et al., 2002).

A different automated system presented by Harmanani, Zouein, and Hajar (2000); Zouein et al. (2002) defines genetic algorithm based site layout without using a grid system. As such, the location of facilities, or their size, is not constrained to the grid. A closeness weight is assigned to pairs of facilities, measured based on flow, or unit transportation cost between them. An interesting feature of this automated system is its ability to imply a minimum or maximum distance between facilities and constrain a facility to have the desired surrounding facilities on its four main sides (i.e. North, South, East, and West). Also, the orientation (0 or 90 degrees) and non-overlap constraints can be applied to the facilities. The automated system utilizes a larger number of genetic algorithm operators to achieve better results, and implements constraints other than minimum travel distance as mentioned before. However, the system is infrequent to be applicable for construction sites because it defines the layout as a bin-packing-like problem. Optimally, this class of problems results in tightly packed layouts. In construction sites, facilities are not tightly packed, and even in congested sites, spaces are left between facilities to provide access. Adding to that, the system does not introduce a method to implement fixed facilities on site in order to setup conditions of construction sites and facilities are defined only in rectangular forms.

Elbeltagi et al. (2004) present their automated system for dynamic site layout planning in construction that assists in maintaining safety and productivity on construction sites. This automated system determines the schedule dependent site needs of temporary facilities. Accordingly, it optimizes the site plans needed at different intervals along the construction duration. To determine the needed temporary facilities on site in any time interval (between any two schedule dates), a five-steps approach is used: (1) necessary temporary facilities must be identified and sized; (2) a schedule of the

construction process must be assembled; (3) the activities' requirements of the temporary facilities are defined, similar to the requirements of labor, equipment, and other site-specific resources. In this sense, the selected temporary facilities are dealt with as resources that are assigned to activities; (4) the service times for each temporary facility temporary facilities are then determined from the schedule (A service time is the time from facility start time (FST) to facility finish time (FFT)); and (5) the temporary facilities that serve any time interval can be defined and considered as the needed temporary facilities on site in this interval.

It is worth knowing that the changing and reorganizing of the site layout on frequent terms can cost much. Accordingly, in the Dynamic Site Layout Planning, reducing the cost of reallocating temporary facilities is achieved in a simple process in order to minimize work disruption. Thus, the location of a layout will not be changed if a temporary facility that has been placed on the site in a previous layout is still needed. That is why, the temporary facility that is required in subsequent layouts will be considered to have a fixed location (called fixed facility).

To incorporate both safety and productivity aspects into site layout planning, this automated system involve four aspects: defining the temporary facilities needed for safety reasons and to support construction operations; defining proper safety zones around construction spaces; considering safety in determining the optimum placement of facilities within the site; and dynamically changing the temporary facilities uses and also using parts of the completed permanent space as temporary facilities, to alleviate site congestion.

However, representation of the temporary facilities has been much simplified and facilitated, facilities are represented as a number of small grid units that can take

irregular shapes. The area of each grid unit is calculated as the greatest common divisor (GCD) same as Hegazy and Elbeltagi (1999), i.e., the largest integer that divides without remainder, of all facilities' areas. For example, if three facilities have areas of 50, 120, and 90 m<sup>2</sup>, then the GCD is 10 m<sup>2</sup>. Accordingly, the site is divided into a grid with unit area of 10 m<sup>2</sup>. With the site grid known, each cell gets a location reference that is calculated as the cell location reference = (cell row-1) × site column + cell column. Using this location reference, a temporary facility can be placed on the site grid, either horizontally or vertically.

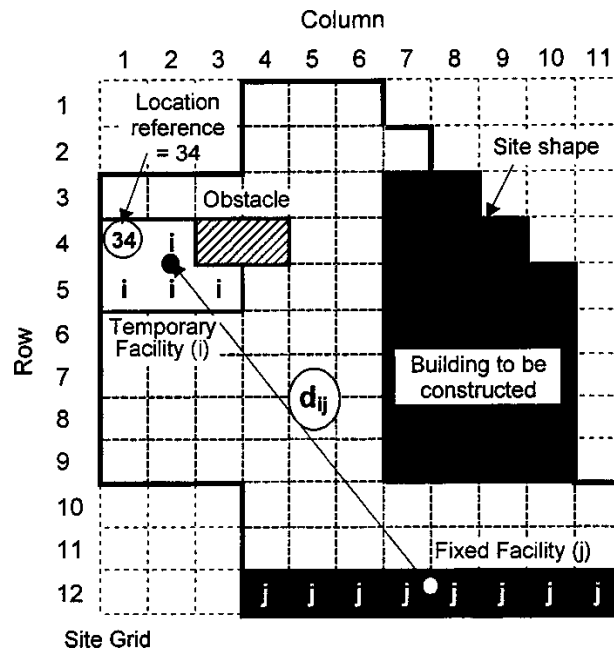


Figure (2. 4): Site and facility representation (Elbeltagi et al., 2004).

As shown in figure (2.4) the method used in calculating the distance between the facilities (Euclidean: center-to-center distances) does not express the real distance in real life which governed by actual site paths. The automated system also deals with safety considerations only and environmental aspects are not considered.

A site layout planning automated system is developed by El-Rayes and Khalafallah (2005) to allow the simultaneous optimization of construction safety and travel cost

of resources on site. This automated system is modeled to search for and generate optimal site layout plans. This will provide optimal trade-offs between these two important objectives with the consideration of all practical constraints in this construction problem. This system was developed in three main phases: 1) formulating decision variables and optimization objectives; 2) identifying and formulating all practical constraints; and 3) implementing the system as a multi objective genetic algorithm. The automated system incorporates three newly developed performance criteria to enable the quantification and maximization of construction safety. These safety criteria are designed to 1) improve the safety of crane operations by selecting safe locations for temporary facilities around cranes; 2) control hazardous material on site by providing adequate separation between combinations of temporary facilities that can create hazardous conditions; and 3) reduce intersections between heavily traveled routes of resources to minimize the potential of accidents and collisions that can occur in these points.

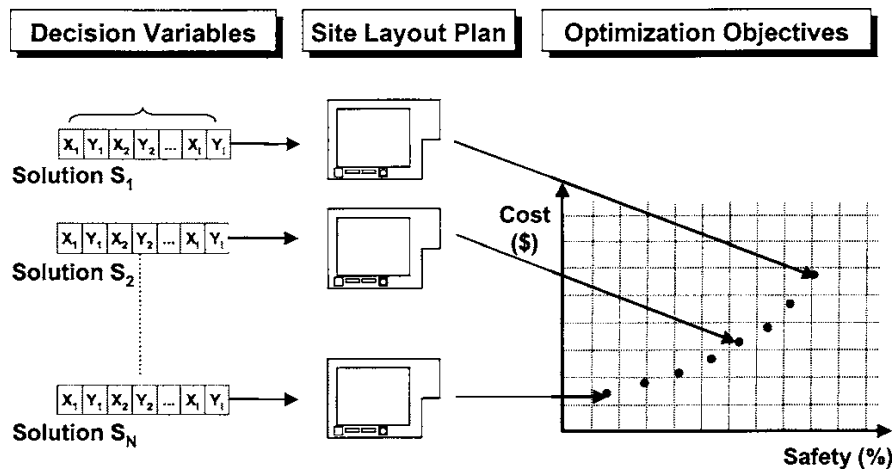


Figure (2. 5): system formulation (El-Rayes & Khalafallah, 2005).

Two types of constraints are imposed in this automated system to generate solutions to ensure the development of practical site layout plans: 1) boundary constraints; and 2) overlap constraints. The main aim of boundary constraints is to guarantee the fact



that temporary facilities are located within the site boundaries, while avoiding the overlap of facilities on site can be achieved through the overlap constraints.

This automated system is utilized to optimize the site layout to increase construction safety and decrease the travel cost of resources on site, while satisfying the earlier described boundary and overlap constraints. Several layouts generated with the impact of trade-offs between construction safety and cost (Figure 2.5). Construction planners can evaluate this optimal trade-off between construction safety and travel cost of resources, and select a site layout that satisfies the specific requirements of the project being considered. However, the system does not consider closeness constraint or environmental aspects and construction facilities can be represented as rectangle shapes only.

Sanad et al. (2008) develop an optimization automated system for solving the site layout planning problem considering safety and environmental issues. The considered issue for the safety and environmental aspects are: prohibited area, safety zones around constructed facilities, and minimum distance between facilities. The site and facilities are formulated in this study using a two dimensional grid. Each grid unit is called a cell, the area of which is user-defined (Figure 2.6).

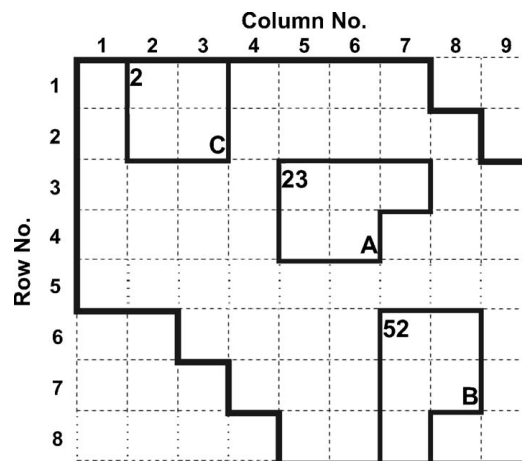


Figure (2. 6): Site and facilities representation (Sanad et al., 2008).

A new method for measuring distance between facilities is used, named as “actual route distance” which is controlled by the actual site paths and routes networks defined by project manager (Figure 2.7). The interrelationships among facilities are decided by the project manager’s preference and they are usually referred to as closeness relationships, which can be represented by closeness (proximity) weights. the high proximity weight between two facilities means that they have a high level of interaction in common and therefore the distance between them should be small.

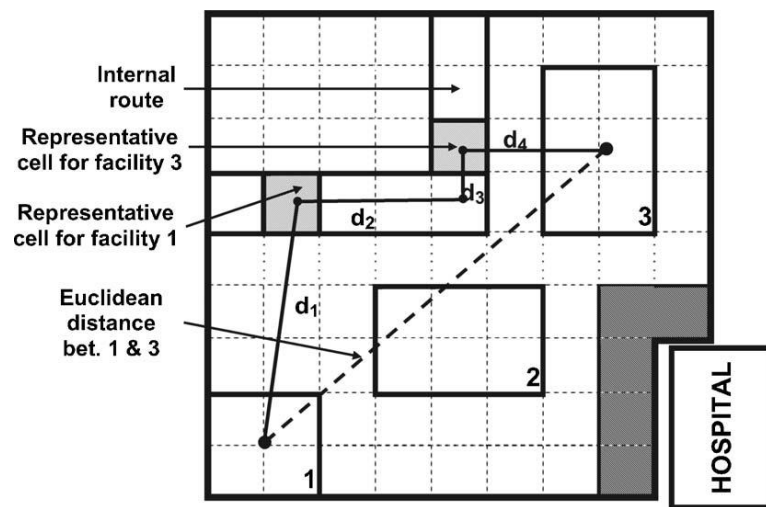


Figure (2. 7): Prohibited areas and shortest route distance (Sanad et al., 2008).

This automated system can also support the dynamic nature of construction projects by integrating with MS Project<sup>®</sup> (Microsoft Corporation, 2000). The system is implemented on a spreadsheet (Excel<sup>®</sup>) (Microsoft Corporation, 2002) because of its simplicity in use and programmability features. The program was coded using the macro-language of Microsoft Excel. Although the system deals with any irregular user-defined site boundary, it is still using two-dimensional grid.

In (2011), Khalafallah and El-Rayes present another automated system. The primary objective of this system is to provide a practical automated support for construction planners and airport operators in optimizing site layout plans. To this end, this system

is designed to provide a number of unique and practical capabilities, including: (1) utilizing multi-objective genetic algorithms in order to enable the simultaneous optimization of construction safety, construction-related aviation safety, construction-related airport security and the overall site layout costs; (2) automating the development of tradeoff charts among construction safety, aviation safety, airport security and the overall site layout costs; and (3) supporting the visualization of the generated optimal site layout plans through seamless integration with commercially available CAD<sup>®</sup> (Autodesk Inc.) software systems.

The system is implemented and integrated into four main components: (1) a comprehensive multi-objective optimization engine that integrates and optimizes the overall impact of site layout planning on construction safety, a construction-related aviation safety, a construction-related security, and all relevant site layout costs; (2) a relational database to support storing and retrieving construction site layout data and the generated optimal solutions; (3) an Input/Output module that facilitates the input of project data and the retrieval of the generated optimal site layout solutions; and (4) a visualization interface that communicates with external CAD software in order to provide construction planners with the capability of visualizing the generated optimal site layouts, as shown in Figure (2.8).

Despite the aforementioned capabilities, this system has the following limitations in: (1) Locating facilities using two-dimensional rectangles, (2) representing site boundaries by straight lines that could be oriented, (3) approximating travel routes between site facilities as the center-to-center distance, and (4) assuming that requirements of site are existing and static, (5) intense specialization in one type of projects (airport project).

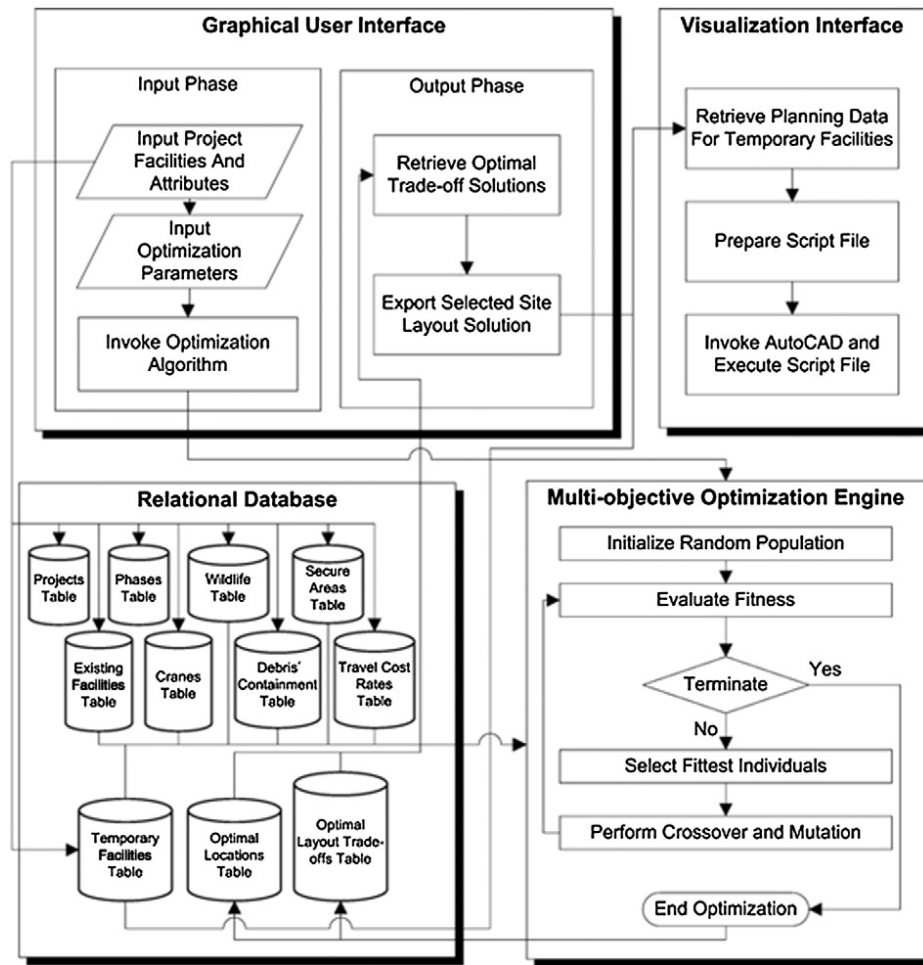


Figure (2. 8): Main modules of the multi-objective optimization system (Khalafallah & El-Rayes, 2011).

A recent study conducted by Said and El-Rayes (2013) introduces an automated system utilizes Genetic Algorithms that is capable of performing an effective and efficient optimization of the dynamic planning of construction site layout. Moreover, to overcome the future effect problem in current automated systems, the effects of first stage layout decisions should be considered on the layouts of subsequent stages. This system generates dynamic site layouts by making and updating the decisions on the locations and orientations of the temporary facilities in every construction stage. The system identifies the position-able facilities, in each stage, that includes: 1) all moveable facilities that continue on site from the previous stage; and 2) all new

moveable and stationary facilities that are used for the first time in this stage. It should be noted that moveable facilities are identified as position-able facilities in all stages where they exist while stationary facilities are identified as position-able facilities only in the first stage when they are needed on site.

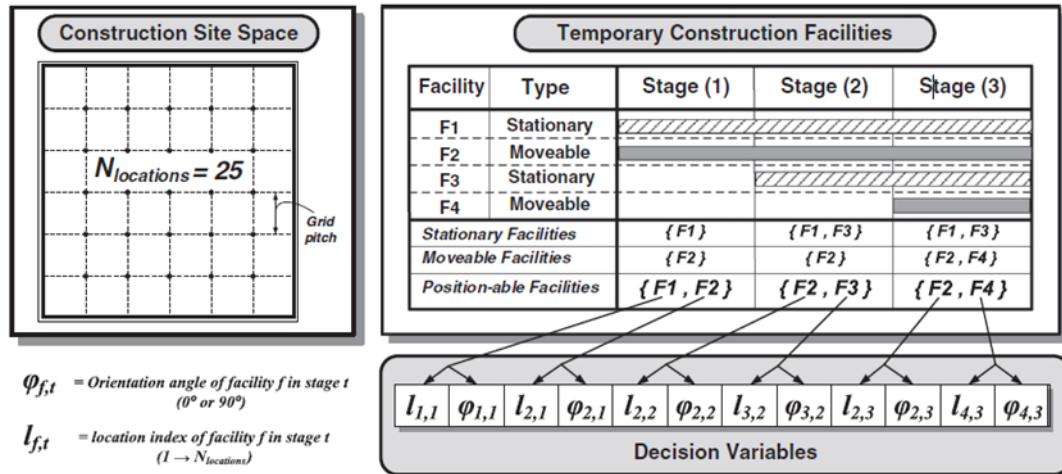


Figure (2. 9): Decision variables and GA string representation (Said & El-Rayes, 2013).

Accordingly, the decision variables are the location and orientation (either  $0^\circ$  or  $90^\circ$ ) of each position-able facility in every construction stage (Figure 2.9). Each facility is positioned in one of the grid positions that are defined based on the grid pitch specified by the planner. But this system considers dynamic site layout planning as an optimization problem with a single objective function of minimizing the total site layout cost. In addition, it represents the construction site and the facilities as a 2D rectangular space, while dealing with the site layout problem as an equal area of grids.

### 3. Knowledge Based Systems

The notable advances in knowledge-based reasoning in the past decades have provided the ability to focus on representation and reasoning in layout problems (Chinowsky, 1991). Expert Systems are knowledge-based (KB) programs in which heuristic

strategies developed by human experts are used to solve domain specific problems. Knowledge structure and representation have a direct influence on the performance of the KB system. Building the knowledge base requires a description of problem-specific, as well as relevant design knowledge. This knowledge includes theoretical information, as well as practical domain knowledge, which is extracted from human domain experts. As a result, these systems promise to provide solutions that have the same quality as domain expert solutions (Luger & Stubblefield, 1989). The main advantage of KBESs is that it enables researchers to address problems for which no algorithmic solution exists.

Knowledge acquisition is often referred to as the bottleneck of expert system development (Hamiani, 1987). This is due to the fact that it is hard to structure the procedure of the experts' decision-making. This makes it difficult to isolate and describe the reasoning procedure (Tommelein, 1991). When developing expert systems, rules and expertise are gathered through interviews with experts. This knowledge is then interpreted by a knowledge engineer into codes that are understandable by expert systems. There is always a risk of the knowledge getting lost or misinterpreted through the way from experts to knowledge engineer and expert system and requires a great expert. Furthermore, it is inconvenient to add new rules to the system posterior to the system implementation. The problem arises when new rules conflict with existing ones. It is essential for a feasible site layout system to be able to accommodate new rules easily, as in practice the rules and constraints change from one project to another. Beside that these rules used in knowledge based systems are not directly integrated, which makes the reasoning of the rules time consuming (Sadeghpour, 2004).

The most famous construction site layout knowledge-based automated systems are Consite (Hamiani, 1987, 1989; Hamiani & Popescu, 1988), SightPlan (Tommelein, 1992; Tommelein, Levitt, Hayes-Roth, & Confrey, 1991; Tommelein, Levitt, & Hayes-Roth, 1992b), MovePlan (Riley & Tommelein, 1996; Tommelein, 1991; Tommelein & Zouein, 1992; Tommelein et al., 1992; Tommelein, Dzeng, & Zouein, 1993; Tommelein & Zouein, 1993a, 1993b; Zouein, 1996), and MoveSchedule (Zouein, 1996; Zouein & Tommelein, 1993, 1994a, 1994b, 1999, 2001) which is the most recent one. MoveSchedule is considered an extension of MovePlan, which constructs an activity schedule to meet the spatial constraints of the site while minimizing the duration of the project. It automatically resolves spatial conflicts by making space-time tradeoffs through a heuristic procedure. The knowledge base of the system holds project data, activity data and resource data. However, linear programming is used to find the optimum location for objects (Zouein & Tommelein, 1999).

In MoveSchedule, resources are clustered in two categories: those that are associated with activities (time-dependent) and those that are not (time-independent). Time-dependent resources are again divided into two groups: consumable and productive. Productive resources (e.g. crane) set the rate of activity production (Zouein & Tommelein, 1993, 1994a). MoveSchedule makes many simplifying assumptions regarding resource modeling. For example, resource representation is limited to rectangular forms; mobile resources are considered fixed in their average position; and mobilization and demobilization times are considered to be zero (Zouein & Tommelein, 1994a). In MoveSchedule, the consumption rate of resources is modeled for the reason of space needed calculations (Zouein, 1996; Zouein & Tommelein, 2001).

Sadeghpour et al. (2006) propose a CAD-based automated system to solve Constructing Site Layout Planning problems. The developed automated system performs its task at two levels: site representation, and site space analysis and allocation. The site representation is carried out using an open architecture supported by object-based concepts. The automated system offers three tiers of objects: (1) site objects, (2) construction objects, and (3) constraint objects. This structure facilitates the creation of new objects and reuse of domain knowledge, which allows for the gradual expansion and enrichment of the system's knowledge base. For the space analysis and allocation level, the system introduces a geometric reasoning approach to analyze site space for finding an optimum or near-optimum location for facilities. This feature facilitates easy visualization of the site planning process and encourages user participation. The automated system is structured in three main modules: Database, Project Module, and Layout Control Module. The functionality of each module, along with their interconnectivity is described. The system is implemented using Visual Basic for Applications in AutoCAD® (Autodesk Inc.) environment and Microsoft Access® (Microsoft Corporation, 2003).

#### 4. NEURAL NETWORKS

Neural networks are a family of massively parallel architecture that solve problems by the cooperation of simple, but are highly interconnected computing elements called neurons (Wasserman, 1989). The main drawback of traditional neural networks for optimization problems was getting trapped in local optimum. Simulated annealing is a probabilistic hill-climbing search algorithm that was proposed to solve combinatorial optimization problems. Random changes are allowed in the simulated annealing technique to escape the local optimum; however, it requires unacceptably long computation time (Yeh, 1995).



SitePlan by Yeh (1995) is a site layout automated system that applies a hybrid type of Neural Networks called Annealed Neural Networks (ANN). Annealed Neural Networks inherits features of both NN and simulated annealing; like simulated annealing, it does not get trapped in local minimum, while exhibiting rapid convergence of the network. SitePlan shows that site layout has to do with a problem of finding the best location for a set of equal size rectangles in a set of predetermined locations on site (Figure 2.10). To encode such a representation, SitePlan uses an  $n \times n$  permutation matrix, in which  $n$  refers to the number of facilities and predetermined locations on site. This representation is obviously an extreme simplification to the reality of construction sites where facilities come in all shapes and sizes and can be placed anywhere on the site.

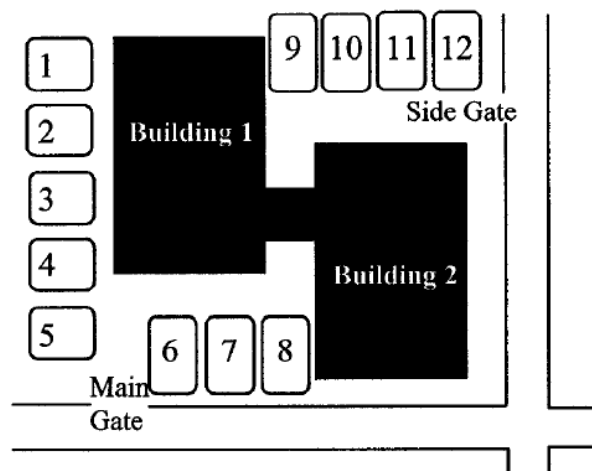


Figure (2. 10): Site space representation in SitePlan (Yeh, 1995).

The main advantage of neural networks for the site layout problem is that the structure of neural networks is capable of easily accommodating multiple constraints. However, in SitePlan, the problem has been formulated as the sum of two costs: construction cost (i.e. cost of assigning a facility on one of the predetermined locations on site) and interactive cost (i.e. cost of assigning facility X on a location neighboring facility Y).

There is also a penalty factor defined to prevent two facilities from occupying the same location. These costs should be determined by the user at the setup stage. The suggested factors to be considered include adjacency of the facilities, the distance between them, availability of space, their position relative to other facilities and view from other facilities. Such predetermination of the construction and interactive cost are not easy and require professional experience to adjust annealed neural networks related setup factors such as initial temperature. While these factors affect the quality of the layout and speed of convergence, they can be confusing for site planners with little or no annealed neural networks knowledge.

## 5. ANT COLONY

Ant colony optimization (ACO) algorithm, which is one of Swarm Intelligence algorithms, that used to offer solutions to facility layout problem in construction site and single layout problem in flexible manufacturing system recently (Lam, Ning, & Ng, 2007). Until 2005, the application of the ant colony optimization algorithm confined to solve static construction site layout problems (Solimanpur, Vrat, & Shankar, 2005). ACO algorithms are population-based, general search technique for the solution of difficult combinatorial problems and inspired by the pheromone trail laying behavior of real ant colonies (Stützle, 2005).

Ning, Lam, and Lam (2010) developed a continuous dynamic searching scheme to guide the max-min ant system (MMAS) algorithm, which is one of the ant colony optimization (ACO) algorithms. It is used to solve the dynamic construction site layout problems under the two congruent objective functions of minimizing safety concerns (minimizing the representative score of safety/environment concerns) and reducing construction cost is proposed (the total handling cost of interaction flows between the

facilities associated with the construction site layout). The system applies the max-min ant system according to these steps: 1-Define the heuristic information, 2-Select assignment sequence for the facilities, 3-Assign facilities to a location.

Apart from the above-mentioned steps using the max-min ant system, the optimization process also involves the following steps: first, identify the dynamic layout intervals and facilities serviced in each time interval in accordance with the project planning. Second, calculate the closeness relationship between the facilities. Third, define the multiple objective functions. Fourth, define the dynamic searching scheme to guide the optimization algorithm to layout the same facilities serviced in the different dynamic time intervals. Having these four steps defined, the max-min ant is then employed to find locations for the facilities serviced in the different construction phases.

Since two objective functions defined in this study, the following equation used to convert them to a single objective function:

$$f = w_1.f_1 + w_2.f_2 \quad \text{equation (2. 1)}$$

Where,  $w_1$  and  $w_2$  are the weights of the two objective functions respectively. The proposed method using max-min ant system to solve dynamic construction site layout planning could then be used to find the solution using the single objective function.

The continuous dynamic searching scheme used in this system must arrange all facilities for the whole construction period to be positioned on a single site layout which may considered as static layout (Figure 2.11). Although reallocating the facilities during the project duration cost money, it may lead to better layouts.

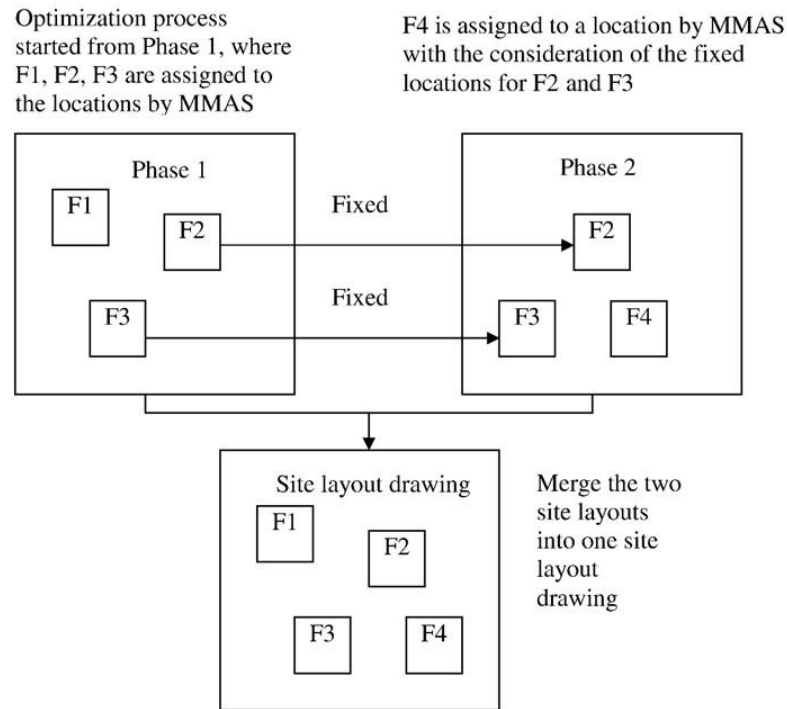


Figure (2. 11): Continuous dynamic searching scheme (Ning et al., 2010).

A hybrid automated system presented by (Lam et al., 2009) is designed based on the max-min ant system in conjunction with genetic algorithms (MMAS-GA). Because the attempt to find the solution of randomly generated initial population problem in genetic algorithms may decrease solution quality. Thus, the max-min ant system is adopted to offer a better initial population. This hybrid optimization algorithm is proposed to solve equal-area construction site layout problem.

The results of MMAS-GA and traditional genetic algorithms are compared to reveal the computational capability. The results show that the proposed MMAS-GA algorithm provides a better optimal solution under the objective function of minimizing the transportation flows between the site facilities. However, this result is under certain circumstances like a single object and an equal-area problem and it may change if any of these circumstances change. Also, the number of facilities used is so limited, only 9 facilities are considered in order to simplify the complexity of the

problem with 3 fixed locations for 3 of the facilities (site office, material hoist, and main gate) (Figure 2.12).

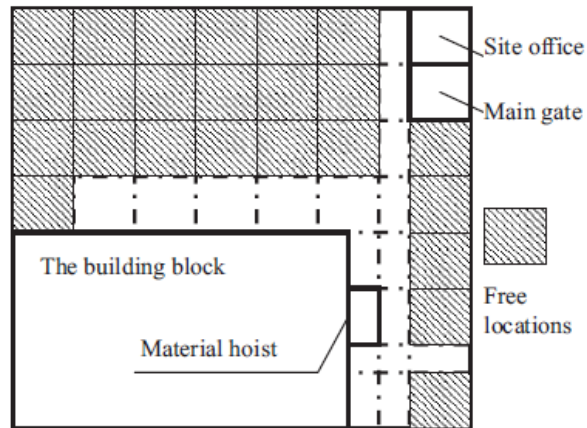


Figure (2. 12): Simplified layout of the hypothetical construction site (Lam et al., 2009).

Ning and Lam (2013) use the Pareto-based Ant Colony Optimization (ACO) algorithm to propose their multi-objective optimization automated system to solve the unequal-area construction site layout planning problem (Figure 2.13). The aim of the proposed multi-objective optimization automated system is to find cost and safety trade-off design for construction site layout. Thus, two objective functions are set in this study. The first objective function defined is to minimize the likelihood of accidents happening in order to improve the overall safety level and the second objective function defined is to minimize the total handling cost of interaction flows between the facilities associated with the construction site layout. However, this system has a significant drawback in generating static site layouts.

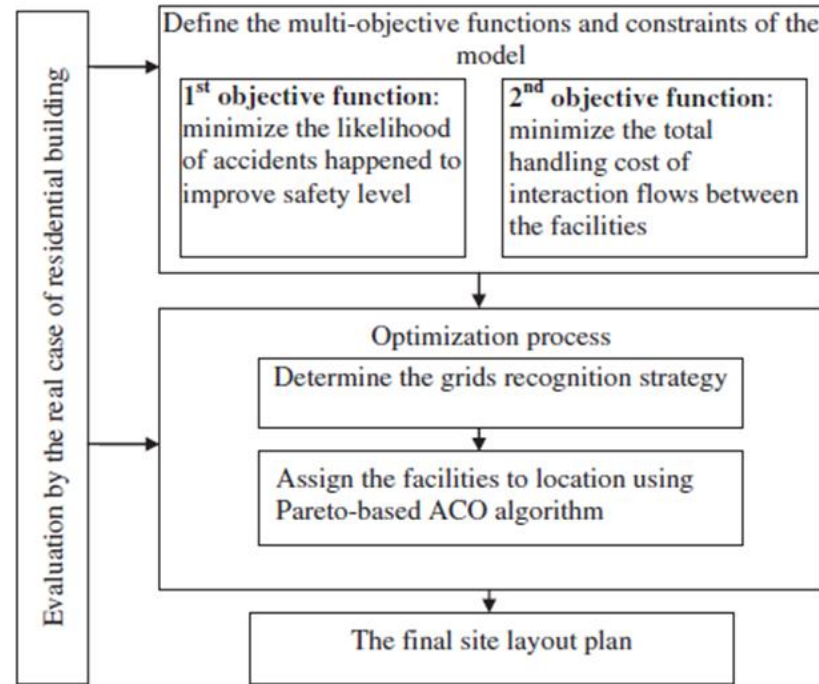


Figure (2. 13): The structure the proposed multi-objective optimization automated system using Pareto-based ACO algorithm (Ning & Lam, 2013).

## 6. Bee Colony

The Artificial Bee Colony algorithm (ABC) is a swarm intelligence algorithm proposed by (Karaboga) in 2005, which is inspired by the behavior of honey bees. Since the development of ABC, it has been applied to solve different kinds of problems such as the site layout planning problems.

Yahya and Saka (2014) developed a multi objective artificial bee colony (MOABC) via Levy flights algorithm to determine the optimum construction site layout. This system is intended to optimize the dynamic layout of unequal-area under two objective functions. The first objective function is to minimize the total handling cost of interaction flows between facilities. The second is to minimize safety hazards/environmental concerns. Although, this system introduces some of new practical capabilities such as 1) utilizing of two objective functions; 2) calculating the

actual travel distances between facilities; and 3) allowing for facilities to be aligned vertically or horizontally. However, it still has some serious shortcomings such as employing the continuous search scheme as a space search approach to locate the site facilities. The continuous search scheme does not allow for the site facilities to be relocated during the various project phases. Accordingly, the arrangement of facilities for the whole construction period can be positioned on a single site layout which may be considered as a static layout (Figure 2.14). Although the reallocating of facilities during the project phases may cost money, it can lead to better layouts. Furthermore, this system represents the site facilities as 2D regular shapes only.

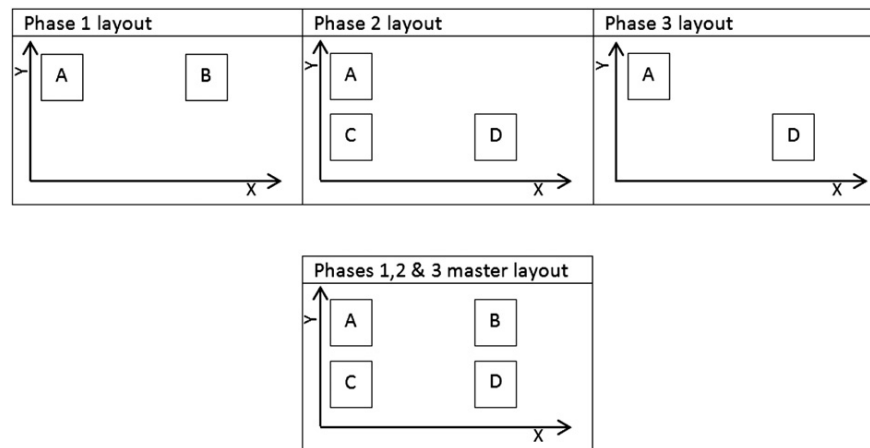


Figure (2. 14): Continuous dynamic search scheme (Yahya & Saka, 2014).

## 7. Integer Linear Programming

The integer linear programming problem is a mathematical optimization techniques which utilized to optimize different kinds of problems such as the site layout planning problems (Montreuil, 1990).

Huang and Wong (2015) introduce a binary-mixed-integer-linear program system. The mathematical objective function of this system aims to minimize the total cost, which consists of the material transportation cost between the relevant site facilities

and the dismantling, setup and relocation costs for all of the involved site facilities in each construction stage. This system model the safety design requirements and considerations in the form of simple linear constraint sets. However, this system has significant drawbacks in representing the site facilities as 2D regular shapes only, single objective function and does not allow the space reuse in the same construction stage.

## 8. Discussion

After exploring the pervious automated systems, it is apparent that there are limitations and shortcomings in the existing automated systems which create a gap between what has been developed from the body of knowledge and what is needed by the industry. This gap is featured by the limitations and shortcomings of the existing automated systems to include a single objective, integrating with regular facilities and site areas only, 2D site layouts representation, inefficient approaches to reflect the dynamic nature of construction sites, ignoring space reuse and facilities relocation, equal area space search, generating static layout, do not cover end users' requirements, being built on real factors measured from sites, highly complex for users, ignoring the user interaction, and lacking of flexibility in the system design. Consequently, they cannot be applied to other cases, but only the case they are designed for. Therefore, it is within the intention of the research to introduce a new automated dynamic site layout planning system to fill this gap by covering the shortcomings and limitations of the existing automated systems as well as providing requirements that are measured from real sites.



## 2.6. SUMMARY AND CONCLUSIONS

This chapter has presented explanation for two of the main objectives of the research, that are, to develop an understanding of site layout planning within the construction industry, explore its current practices and challenges as well as to explore existing automated systems to define their limitations, shortcomings and the successful utilizations that can be incorporated within the proposed automated system. Below is a summary of the main key points gained from the literature reviewed relevant to the two main objectives mentioned before:

- Literature review shows that there are a number of definitions for construction site layout planning, however, this research will define the construction site layout planning task as (finding the optimal layout for construction sites according to facilities duration, constraints and objective's demand by each project).
- The construction industry has several aspects that need a continual improvement to avoid its negative influence on the industry.
- Site layout planning is one of the construction industry problems that need more attention and development.
- Site layout planning is often ignored or overlooked in construction sites which leads to negative impact on the safety, productivity, cost, time, waste materials and surrounding environment of construction projects.
- Efficient layout planning of a construction site is fundamental to any successful project undertaking.
- Automated systems can be considered as the most effective methods to develop an efficient site layout as they fully cover all concerns that cannot be taken into account by manual methods.

- The existing automated systems have a lot of limitations and shortcomings that need to be covered.
- There is a need to improve the site layout planning by developing new automated system to generate more efficient site layout, cover the existing automated systems limitations and shortcomings as well as consider the end user's requirements.

This chapter has presented partial findings for the first stage of this research which is the pre-development stage. Therefore, the following chapter will assess the site layout planning in the real Egyptian construction sites for more clearly formulate an explicit and precise research problem and setting the proposed automated site layout planning system tool and technique. Chapter 4 will develop the research methodology. Based on this methodology, Chapter 5 will introduce the structure and characteristic of the proposed multi objective automated site layout planning system, while chapter 6 will implement, validate and evaluate the proposed automated system.

## **CHAPTER 3**

### **TOOLS AND TECHNIQUES FOR THE PROPOSED AUTOMATED SITE LAYOUT PLANNING SYSTEM**

#### **3.1. INTRODUCTION**

Chapter 2 argues that the efficient site layout can have a considerable effect on construction sites and the automated systems are the most suitable method to develop it rather than manual methods. It also stresses that the available automated systems have some limitations and shortcomings that can be enhanced by developing new automated systems that cover those limitations and shortcomings. The main aim of this chapter is to assess the site layout planning in the real Egyptian construction sites for more clearly formulate an explicit and precise research problem and setting the proposed automated site layout planning system tool and technique. To achieve this, a survey was undertaken to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real construction sites. Accordingly, the proposed automated site layout planning system tool and technique that will cover the existing systems limitations and shortcomings and the end users' requirements will be selected. Therefore, this chapter first summarizes the existing automated systems limitations and shortcomings based on the findings of chapter 2. Then, the chapter demonstrates the survey and its analysis. The survey data collection methods will be discussed in detail in Chapter 4. The chapter also reviews the tool and technique utilizing to develop the proposed automated system. Finally, this chapter outlines the suitability and benefits of this tool and technique for the proposed automated site layout planning system and explains their theoretical background.

### **3.2. THE EXISTING AUTOMATED SYSTEMS LIMITATIONS AND SHORTCOMINGS**

A comprehensive literature review is conducted in chapter 2 in order to identify and analyze all the relevant site layout-related optimization criteria, challenges, shortcomings and limitations. This leads to the truth that despite the significant contributions and practical features of the developed automated systems, they still have some limitations and shortcomings to work in real constructions sites. These limitations and shortcomings can be summarized as follows:

1. All the available automated site layout optimization systems are incapable of maximizing the protection of construction sites surrounding environment because it is not considered as an important optimization objective in construction site layout planning.
2. Most of the existing automated site layout optimization systems are bounded to fixed single or double objectives and they do not support the simultaneous optimization and analysis of multiple site layout planning objectives.
3. The poor representation of facilities shapes and generates site layouts (2D rectangular facilities shape only, 2D site layouts representation) as well as the static layout modeling approach for construction projects.
4. The previous research work has mainly ignored the user interaction and concentrated on selecting information from their data base, in addition to the complicated interface which is in need of experts to be used.
5. The existing automated site layout optimization systems are modeled rigid, comprised and fixed with some elements such as objectives, facilities and constraints.

In order to address the research problem and set the proposed automated site layout planning system tool and technique, a survey was conducted to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real Egyptian construction sites as will be described in the next section.

### **3.3. THE SURVEY**

The aim of the survey is to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real construction sites as it will be discussed in chapter 4. The survey data collection is done using questionnaires method as it will be discussed in chapter 4. Therefore, main focus of the next sections is to describe the selected sample, the purpose of the questionnaire, response rate and the data analysis method.

#### **3.3.1. Sample**

Based on the criteria of the survey sample that will be discussed in section 4.6, sixteen construction industry practitioners from public and private sectors (8 from each sector) were picked and received the questionnaires. Twelve questionnaires were returned (4 from private sector and 8 from public sector) which achieve of 75% response rate. The response rate of 75% is acceptable and it is in line with the opinions of Akintoye (2000); Dulaimi, Ling, and Bajracharya (2003); Takim, Akintoye, and Kelly (2004). As they reported that the normal response rate in the construction industry for questionnaires is around 20-30 %.

### **3.3.2. The Questionnaire**

The survey data collection is done using questionnaires method as it will be discussed in section 4.6. Questionnaire (Appendix A), utilized to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning of site layout planning from real Egyptian construction sites. To achieve this aim, the questionnaire is divided into four sections as follow:

#### **SECTION I - PROFILE**

This section investigates the profile of the participants involved in the questionnaire through position, years of experience and employer sector. This is due to understanding the effect of their profiles on their responses, by correlating their profiles with their opinion on the importance, objectives, implementation methods, problems, effects, automation and end users' requirements of site layout planning of site layout planning in the real Egyptian construction sites as it will be discussed in section 3.2.3.

#### **SECTION II – SITE LAYOUT PLANNING IMPORTANCE, OBJECTIVES, IMPLEMENTATION METHODS, PROBLEMS, EFFECTS AND AUTOMATION**

Participants were asked to assess the site layout planning importance, objectives, implementation methods, problems, effects and automation in the real Egyptian construction sites. This section summarizes the data collected from participants' responses that reflecting their opinion towards the previously mentioned concerns based on what is executed in real projects. Furthermore, these data will assist in the designing and developing of proposed automated system.

## SECTION III – AUTOMATED SITE LAYOUT PLANNING SYSTEM END USERS' REQUIREMENTS

In order to explore the end users' requirements of the automated site layout planning system, this part of the survey investigated these requirements based on the real Egyptian construction sites that could be covered by the proposed automated system.

## SECTION IV – SITE LAYOUT PLANNING FACILITIES AND RELATIONS

This section investigates the participants' responses to capture the most repetitive facilities in construction site in addition to their sizes and relations to incorporate them in the proposed automated system as a data base that guides its users.

### **3.3.3. The Analysis**

To aid this investigation, the following statistical tests were carried, where appropriate:

- a. Analysis of attributes - Participants' backgrounds were grouped into categories and analysed in percentages, using the SPSS summary of frequency.
- b. Analysis of responses - The percentage of frequency of the data collected from the participants' responses were calculated and tabulated.
- c. The Kruskal-Wallis test - This test is performed to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable (H0: population medians are equal and H1: population medians are not equal).
  - i. If the p-value is less than or equal to the significance level (0.05), then the null hypothesis is rejected and concluded that the group medians are all not equal.

- ii. If the p-value is greater than the significance level (0.05), then the null hypothesis is not rejected as there is not enough evidence to reject and concluded that the group medians are all equal.

The next sections will provide a summary of the results obtained from these tests.

## SECTION I – PROFILE

The participants' profile is described in this section, shown in percentages of frequencies, in figures (3.1; 3.2 and 3.3) with the help of the SPSS summary of frequencies command, namely: position, years of experience and employer sector.

### a. Position

Participants are categorized in three groups; Project manager forming 42%, Technical office manager forming 33% and Site engineer forming 25%.

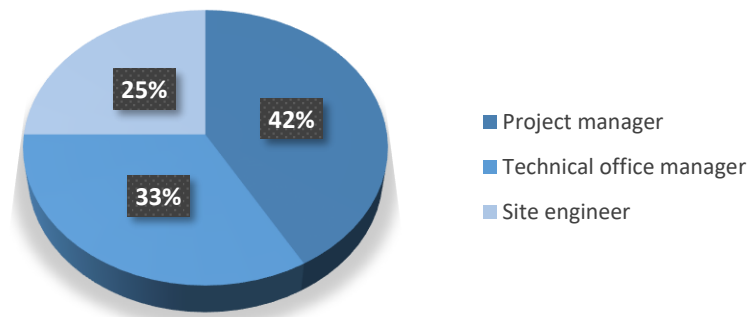


Figure (3. 1): Position.

Such participants' sample are considered as a neutral sample to reflect a balanced response as the participants come from different positions.

### b. Years of experience

Participants are categorised into three groups based on their experience to help achieving more global results, these were; Group 1 (15 to 19 years), Group 2 (21 to



29 years) and Group 3 (More than 29 years). The results have shown that the highest proportion of participants falls in the category of having 15 to 19 years of experience forming 42%, while less falls in more than 29 years of experience category forming 33% and least falling in 20 to 29 years of experience category forming 25%.

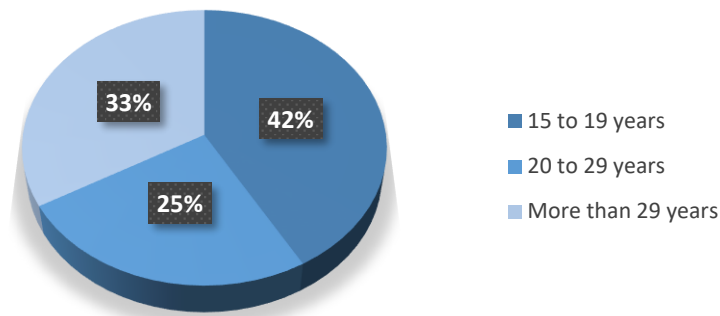


Figure (3. 2): Years of experience.

Such participants' sample are considered as a neutral sample to reflect a balanced response as the participants come from different years of experience. Furthermore, it shows that more than half of the population are more than 20 years of experience which mean getting more experienced feedback.

#### c. Employer sector

Participants are categorised into two groups based on the employer sector; Public Sector forming 67% and Private Sector forming 33%.

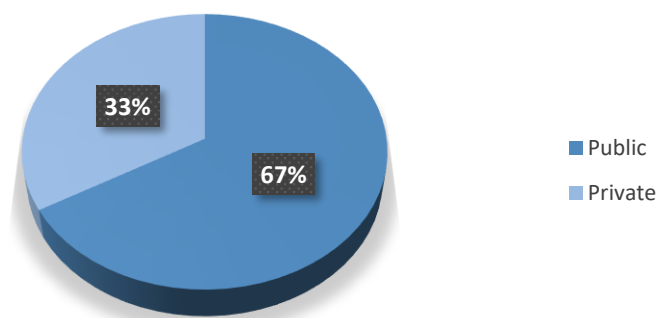


Figure (3. 3): Employer sector.

This clearly indicates the questionnaires high response rate comes from the public sector. This may be a credit for this research as the public sector projects majority are mega projects which definitely include site layouts.

## SECTION II – SITE LAYOUT PLANNING IMPORTANCE, OBJECTIVES, IMPLEMENTATION METHODS, PROBLEMS, EFFECTS AND AUTOMATION

A summary of the data collected from participants' responses is presented in this section. Their opinions are reflected towards the importance, objectives, implementation methods, problems, effects and automation in the real Egyptian construction sites. The relevant statistical tests that discussed before in section (3.3.3) are used to analyse these responses as listed below:

### a. Importance

This section investigates the importance of the site layout planning as one of the project's tasks in real construction sites. The questionnaire survey asked the participants a direct question about the importance of the site layout planning which is "What is the importance of the site layout planning as one of the projects' tasks?". The choices of answers for this question were High, Average, Low and Useless. All the participants (100 %) choose the High importance answer which clearly indicates the importance of the site layout planning as one of the projects' tasks. Furthermore, the SPSS summary of frequencies command is used to analyse the number of questionnaire' participants who actually develop a site layout plan before or participate in projects with a site layout plan before as shown in figure (3.4). The reason behind this analysis is to signify the importance of the site layout planning task based on the extent of actually implemented in real sites through the participants.

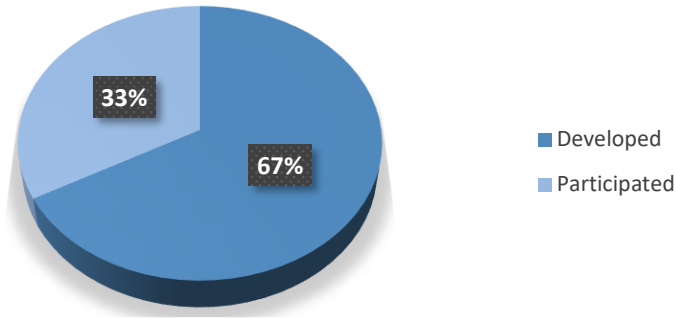


Figure (3. 4): The distribution of frequencies for the participants who developed a site layout plan before or participated in projects with a site layout plan before.

The distribution of frequencies of the participants' responses shows that 67% of participants actually developed a site layout plan before, while 33% participated in projects with a site layout plan before. Therefore, the results show that the majority of participants has developed a site plan before. Furthermore, it indicates the importance of implementing site layout plans in real construction sites.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.1).

Table (3. 1): The Kruskal Wallis test for the participants who developed a site layout plan before or participated in projects with a site layout plan before.

<b>The percentage of the questioner participation who developed a site layout plan before or participated in projects with a site layout plan before</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
The percentage of the questioner participation who developed a site layout plan before	0.662	0.228	0.407
The percentage of the questioner participation who participated in project with a site layout plan before	0.662	0.228	0.407

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants' responses were not affected by their profile.

#### b. Objectives

This section investigates the objectives that can be achieved by an efficient site layout planning, the SPSS summary of frequencies command is used to analyse the given responses. The distribution of frequencies of these responses' scores in figure (3.5) shows that the participants choose *Minimize cost and Improve the site safety* objectives as the highest objectives with score of 91.7 %, then *Minimize time* objective with score of 83.3 %, while *Protect the surrounding environment* objective was the least objectives with score of 75 %.

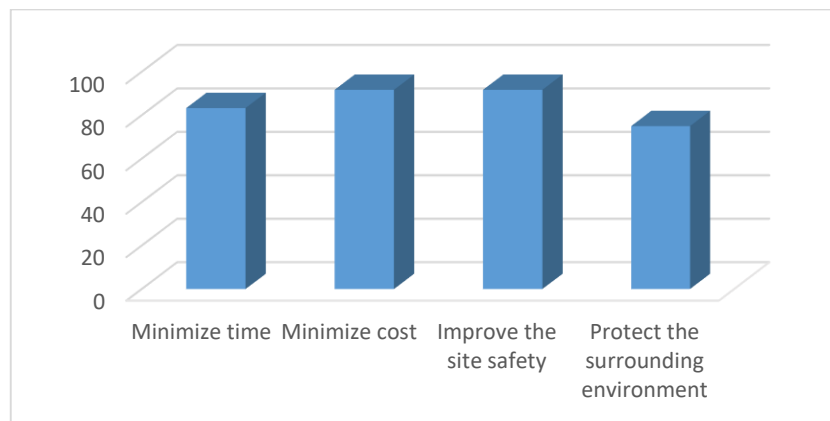


Figure (3. 5): The distribution of frequencies of the objectives' scores that can be achieved by efficient site layout planning.

These results clearly indicate that the site layout planning has multiple objectives in real construction sites which argue the importance of developing multi-objectives automated system. Furthermore, these results show that the real construction sites interest in minimizing the projects' cost and time and maximizing the projects' safety more than protecting the projects' surrounding environment.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.2).

Table (3. 2): The Kruskal Wallis test for the objectives that can be achieved by an efficient site layout planning.

<b>The objectives that can be achieved by an efficient site layout planning</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
Minimize time	0.680	0.111	0.294
Minimize cost	0.497	0.368	0.480
Improve the site safety	0.368	0.368	0.480
Protect the surrounding Environment	0.922	0.333	0.176

The values of Kruskal Wallis indicate that for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

#### c. Implementation methods

This section investigates the site layout planning implementation methods in the real construction sites. The questionnaire survey takes the opportunity to ask participants about the most appropriate stage – of the project's life cycle –for the implementation of the site layout planning task. All the participants' responses (100 %) reveal that the project planning stage is the appropriate stage to develop an efficient site layout plan. Furthermore, 92 % of participants' responses demonstrate that the quality – of the site layout plan – is affected by the stage in which it is implemented in, while 8 % demonstrate that the quality – of the site layout plan – did not affected by the stage in which it is implemented in as shown in figure (3.6). These results confirm that the practice of developing the site layout in construction sites as discussed in chapter 2 may lead to an inefficient site layout.

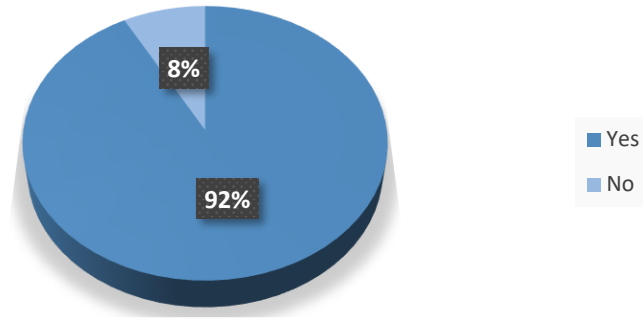


Figure (3. 6): The distribution of frequencies for participants' responses that demonstrate that the quality of the site layout plan is depends or not depend on its implementation stage.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.3).

Table (3. 3): The Kruskal Wallis test for the effect of the site layout plan implementation stage on its quality.

The effect of the site layout plan implementation stage on its quality	Position	Experience	Sector
	0.497	0.368	0.480

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

To investigate who is the most suitable person to execute the site layout planning task, the participants were asked to nominate this person. The participants' responses are categorized into three nominations: Project manager, Technical office manager and Site engineer. The distribution of frequencies of these nominations in figure (3.7) shows that the project manager forming 84 % of participants' nominations, the Technical office manager forming 8 % of participants' nominations., while the site engineer forming 8 % of participants' nominations. It is worth noting that the

discrepancy in responses is noticeably large. Therefore, the results clearly indicate that the project manger is the suitable person to execute the site layout planning task.

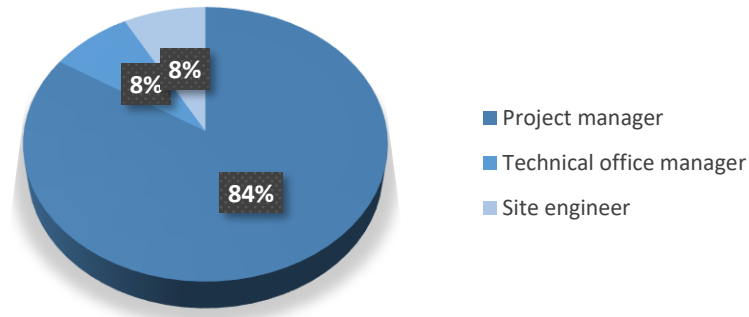


Figure (3. 7): The distribution of frequencies for the participants' responses indicates the nomination for the suitable person to execute the site layout planning task.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.4).

Table (3. 4): The Kruskal Wallis test for the most suitable person to execute the site layout planning task.

The most suitable person to execute the site layout planning task	Position	Experience	Sector
	0.477	0.694	0.296

The values of Kruskal Wallis indicate that for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

Figure (3.8) introduces the distribution of frequencies of participants' responses for what the nominated person depends on to execute the site layout planning task. The distribution of frequencies of these responses' scores shows that the participants choose the *Personal experience* as the highest option with score of 83.3 %, then the *Study group* option with score of 33.3 %, while the *Previous layouts* option is the least

factor with score of 25 %. The SPSS summary of frequencies command is used to analyse the given responses.

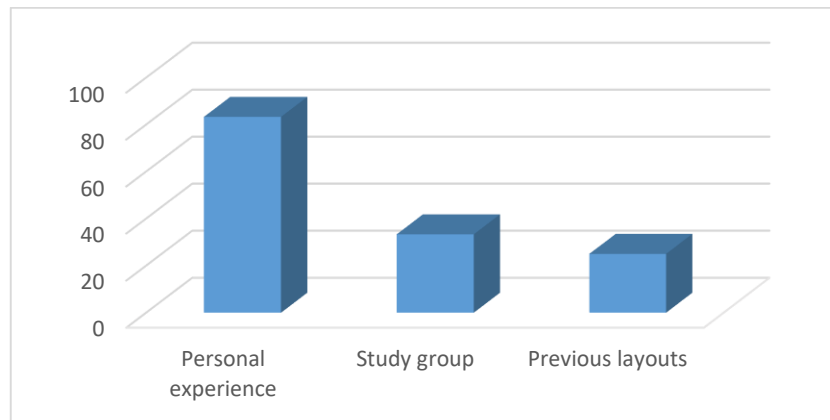


Figure (3. 8): The distribution of frequencies of the participants' scores for what the nominated person depends on to execute the site layout planning task.

Therefore, the results show that the personal experience is a very important factor in developing a site layout plan.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.5).

Table (3. 5): The Kruskal Wallis test for what the nominated person depends on to execute the site layout planning task.

<b>What the nominated person depends on to execute the site layout planning task</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
Personal experience	0.517	0.680	0.294
Study group	0.192	0.662	0.097
Previous layouts	0.004	0.077	1.000

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.



For a closer examination of the type of information that need to develop a site layout plan, the participants were asked to specify this information. The participants' responses are categorized into five needed information: Project schedule, Site boundary and drawings, Needed facilities, Project size and Project budget. The distribution of frequencies of these information scores in figure (3.9) shows that the project schedule score 91.7 %, the Site boundary and drawings scores 100 % of, the Needed facilities scores 75 %, the Project size scores 33.3 %, while the site Project budget scores 33.3 %. Therefore, the results clearly indicate that the needed information to develop a site layout plan arranged according to their importance' scores are Site boundary and drawings, Project schedule, Needed facilities then Project size and Project budget.

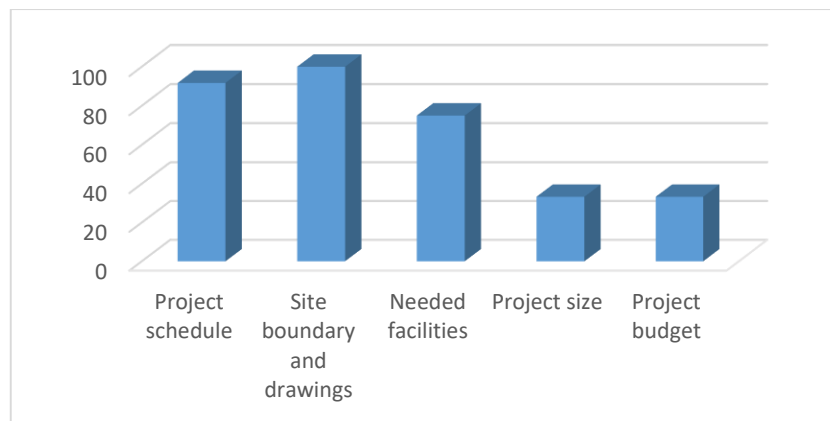


Figure (3. 9): The distribution of frequencies of the participants' scores for the needed information to execute the site layout planning task.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.6).

Table (3. 6): The Kruskal Wallis test for the needed information to execute the site layout planning task.

<b>The needed information to execute the site layout planning task</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
project schedule	0.368	0.368	0.480
site boundary and drawings	1.000	1.000	1.000
needed facilities	0.333	0.922	0.176
project size	0.192	0.382	0.097
project budget	0.192	0.382	0.097

The values of Kruskal Wallis indicate that for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

To investigate the most difficult stage of the site layout planning, the SPSS summary of frequencies command is used to analyse the given responses. The distribution of frequencies of these responses' scores in figure (3.10) shows that the participants choose *Determining the temporary facilities location* stage as the most difficult stage with score of 66.7 %, then *Collecting the needed information* stage with score of 58.3 %, while *Determining the temporary facilities* stage with score of 25 % and *Determining the temporary facilities size* stage is the least stages with score of 25 %.

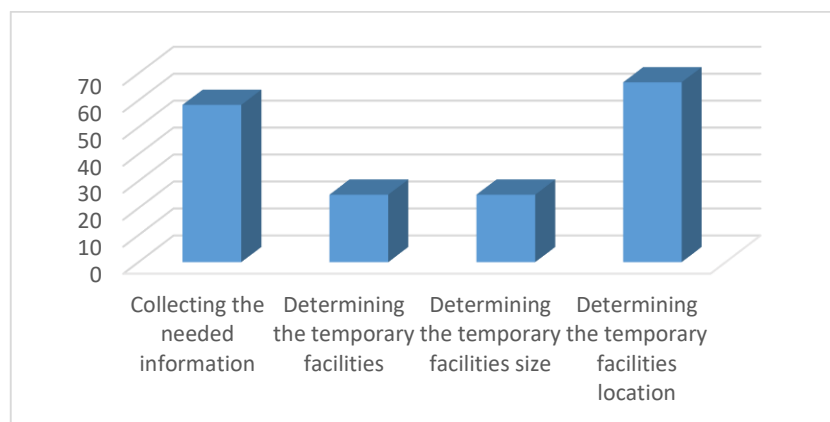


Figure (3. 10): The distribution of frequencies of the participants' scores for the most difficult stage of the site layout planning task.

These results clearly indicate that determining the temporary facilities location stage is the most difficult stage in executing a site layout plan.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.7).

Table (3. 7): The Kruskal Wallis test for the most difficult stage of the site layout planning task.

<b>The most difficult stage of the site layout planning task</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
Collecting the needed information	0.267	0.568	0.113
Determining the Temporary Facilities	0.240	0.392	1.000
Determining the Temporary Facilities Size	0.240	0.077	0.176
Determining the Temporary Facilities Location	0.192	0.382	0.678

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

Furthermore, 83 % of participants' responses demonstrate that the site layout plan needs to be updated with the project's duration, while 17 % of participants' responses demonstrate that the site layout plan dose not need to be updated with the project's duration as shown in figure (311.). It is worth noting that the discrepancy in responses is noticeably large. These results confirm the need to document plan that can be easily updated and modified any time.

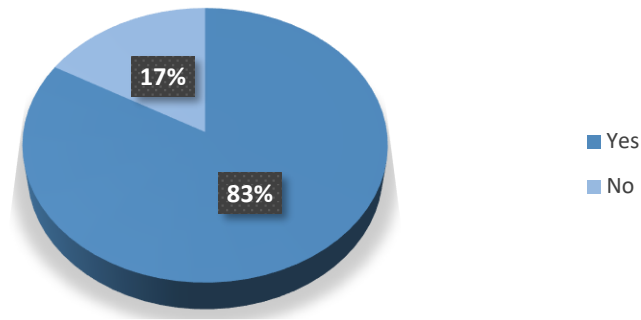


Figure (3. 11): The distribution of frequencies for the participants' responses that demonstrate that the site layout plan must be updated or not updated with the project's duration.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.8).

Table (3. 8): The Kruskal Wallis test for updating the site layout plan with the project's duration.

Updating the site layout plan with the project's duration	Position	Experience	Sector
	0.111	0.438	0.294

The values of Kruskal Wallis indicate that for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

#### d. Problems and effects

This section investigates if the questionnaire participants face any problem resulted from an inadequate site layout planning, the SPSS summary of frequencies command is used to analyze the given responses. The distribution of frequencies of these responses in figure (3.12) shows that 50 % of the participants face problems, while the other 50 % do not face.

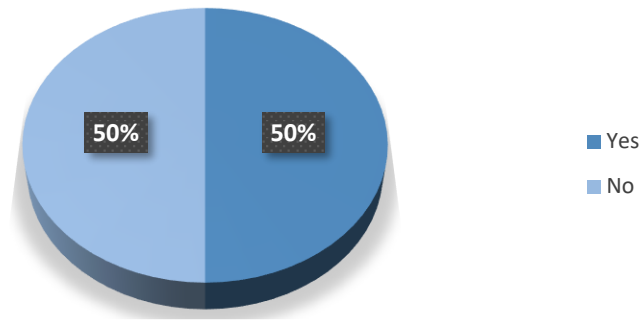


Figure (3. 12): The distribution of frequencies for the participants’ responses that demonstrate if the questionnaire participants face any problems resulted from an inadequate site layout planning.

Although, the distribution of frequencies is equal for both opinions, the frequencies of participants who face problems based on an inadequate site layout planning are still high. These results indicate that inadequate site layout planning may cause problems in real sites.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.9).

Table (3. 9): The Kruskal Wallis test for the problems resulted from an inadequate site layout planning.

Did you face any problem which resulted from an inadequate site layout planning	Position	Experience	Sector
	0.238	0.111	1.000

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants’ responses are not affected by their profile.

Furthermore, all the participants who face problems in construction sites based on an inadequate site layout planning reveals that these problems impact negatively on the project performance.

For a closer examination to the expected effects of site layout plan on the project cost/time, project safety operation and surrounding environment, the participants were asked to specify these effects percentage. The participants' responses are categorized into three groups based on the percentage given for each effect, these were; Group 1 (less than 10 %), Group 2 (10 % to 50 %) and Group 3 (More than 50 %). For the first effect: the effect of site layout plan on the project cost/time, its results in figure (3.13) show that the highest percentage of participants' responses fall in group 2 forming 50 %, while less fall in group 1 forming 33 % and least falling in group 3 forming 17 %.

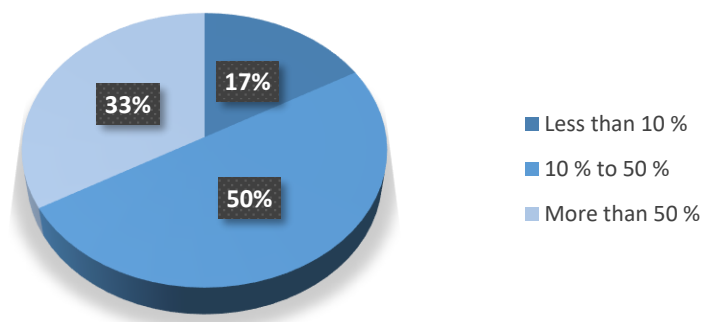


Figure (3. 13): The distribution of frequencies for the participants' responses that demonstrate the effect of site layout plan on the project cost/time.

According to the second effect: the effect of site layout plan on the project safety operation, its results in figure (3.14) show that the highest percentage of participants' responses fall in group 2 forming 75 %, while less fall in group 1 forming 17 % and least falling in group 3 forming 8 %.

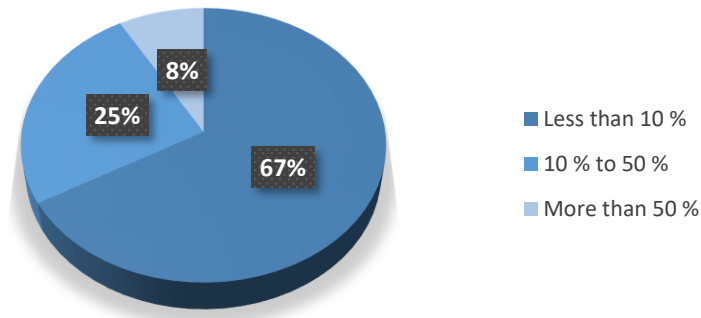


Figure (3. 14): The distribution of frequencies for the participants' responses that demonstrate the effect of site layout plan on the project safety operation.

Finally, for the third effect: the effect of site layout plan on the surrounding environment, its results in figure (3.15) has shown that the highest percentage of participants' responses fall in group 1 forming 67 %, while less fall in group 2 forming 25 % and least falling in group 3 forming 8 %.

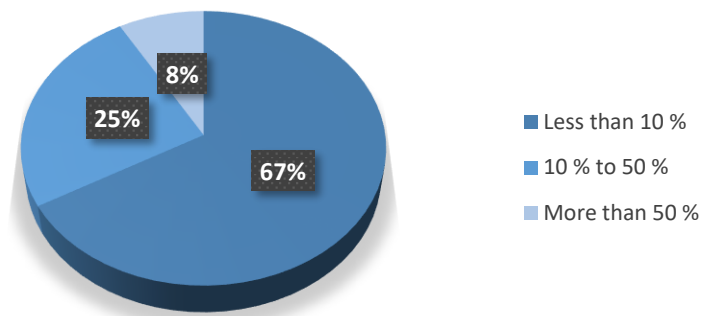


Figure (3. 15): The distribution of frequencies for the participants' responses that demonstrate the effect of site layout plan on the surrounding environment.

These results clearly indicate that the site layout planning effect on the project cost/time and safety operation more than surrounding environment. However, its confirmed that there are effects of site layout plan on the project cost/time, project safety operation and surrounding environment. Table (3.10) presents the mean, mode, minimum and maximum values expressed in percentage for the participants'

responses. It is interesting to see the percentage that expressed the site layout plan effects on the project cost/time, project safety operation and surrounding environment in real sites.

Table (3. 10): The Mean, Mode, Minimum and Maximum values expressed in percentage of the participants' responses.

<b>Statistics</b>	<b>The effect of site layout plan on the project cost/time</b>	<b>The effect of site layout plan on the project safety operation</b>	<b>The effect of site layout plan on the surrounding environment</b>
Mean	34	29.17	14.08
Mode	10	20	0
Minimum	3	5	0
Maximum	90	80	70

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.11).

Table (3. 11): The Kruskal Wallis test for the Mean value of the site layout plan effects.

<b>The site layout plan effects</b>	<b>Position</b>	<b>Experience</b>	<b>Sector</b>
The effect of site layout plan on the project cost/time	0.841	0.083	0.578
The effect of site layout plan on the project safety operation	0.140	0.270	0.118
The effect of site layout plan on the surrounding environment	0.981	0.410	0.919

The values of Kruskal Wallis indicate that for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.



#### e. Automation

The questionnaire survey takes the opportunity to investigate the state of the automation of site layout planning in the Egyptian construction sites. Figure (3.16) presents the participants' responses expressed in percentage. It is interesting to see these results show that 92 % of the participants do not use or hear about the automated site layout planning systems before. While only 8 % actually do. It is worth noting that the discrepancy in responses is noticeably large.

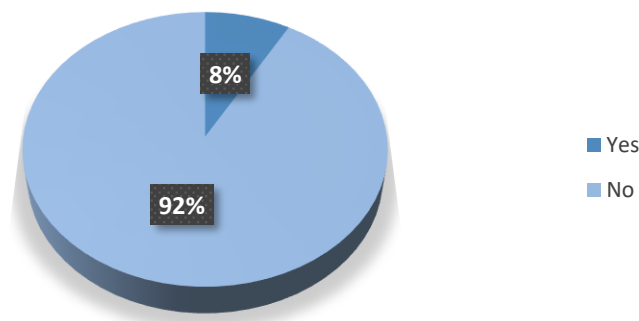


Figure (3. 16): The distribution of frequencies for the participants' responses that indicate the state of the automation of site layout planning in the Egyptian construction sites.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.12).

Table (3. 12): The Kruskal Wallis test for the state of the automation of site layout planning in the Egyptian construction sites.

Did you use or hear about an automated system which is capable of executing the site layout planning task?	Position	Experience	Sector
	0.497	0.368	0.480

Inspection of the table indicates that, for a level of significance of  $> 0.05$ , the participants' responses are not affected by their profile.

Although, the highest proportion of participants' dose not use or hear about the automated site layout planning systems before, when the questionnaire investigates if the participants support such automated systems 58 % of the response are supportive as they think these systems will help. while 42 % are not supportive as they think these systems will not help as shown in figure (3.17).

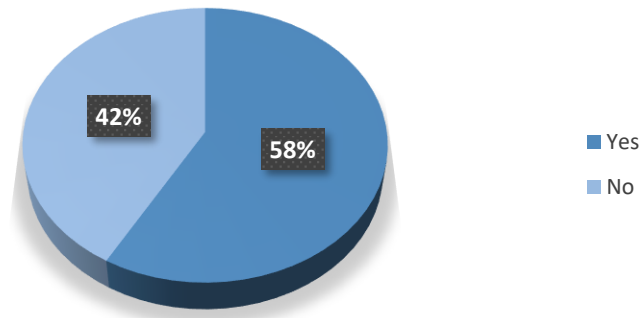


Figure (3. 17): The distribution of frequencies for the participants' responses that indicate their support for the automated systems.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.13).

Table (3. 13): The Kruskal Wallis test for the participants' support for the automated systems.

Do you support such automated systems?	Position	Experience	Sector
	0.428	0.910	0.047

The values of Kruskal Wallis indicate that for a level of significance of  $< 0.05$ , the participants' responses are affected by their employer sector. This may be due to the low budget allocated from the employer in Egypt to spend on the IT tools and training. While for a level of significance of  $> 0.05$ , the participants' responses are not affected by their position or experience.

### SECTION III – AUTOMATED SITE LAYOUT PLANNING SYSTEM END USERS' REQUIREMENTS

This section investigates the end users' requirements in any new automated system.

The participants' responses are categorized into seven main requirements:

1. a user friendly interface to facilitate the usage and inputting needed information.
2. a data bank contains samples of old project and varieties of facilities.
3. the ability to update the layout with the project progresses.
4. a 3D representation for facilities and layouts.
5. a detailed help menu.
6. a dynamic modelling approach.
7. multi-objective function.

Table (3.14) shows the distribution of frequencies of these requirements based on the positive and negative participants' responses with its percentages. It is worth noting that the dynamic modelling approach scores the highest percentage 83.3 % which indicates the need for dynamic systems rather than static systems. Then, the user friendly interface and multi-objective function scores 75 %. While, the data bank scores 58.3 %. According to the ability to update and detailed help menu scores 50 %. Finally, the 3D representation for facilities and layouts scores the least percentage 71.7. %. Therefore, the results demonstrate the end users' needs for robust design for any new automated system which offers practical features and capabilities to execute and update the site layout plan more than offering capabilities in resending it.

Table (3. 14): The distribution of frequencies of these requirements based on the positive and negative participants' responses with its percentages.

The end users' requirements		Frequency	Percentage
1. a user friendly interface to facilitate the usage and inputting needed information	positive	9	75
	negative	3	25
2. a data bank contains samples of old project and varieties of facilities.	positive	7	58.3
	negative	5	41.7
3. the ability to update the layout with the project progresses	positive	6	50
	negative	6	50
4. a 3D representation for facilities and layouts	positive	5	41.7
	negative	7	58.3
5. a detailed help menu	positive	6	50
	negative	6	50
6. a dynamic modelling approach	positive	10	83.3
	negative	2	16.7
7. multi-objective function	positive	9	75
	negative	3	25

The distribution of frequencies for these positive responses' scores are introduced in figure (3.18). However, these end users' requirements will be taken into consideration while designing the proposed automated system to develop a system that could be adopted by construction industry in Egypt.

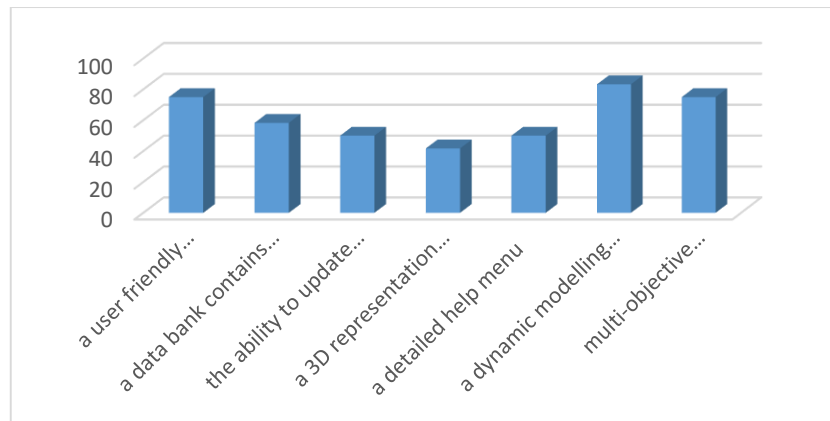


Figure (3. 18): The distribution of frequencies for the positive responses' scores.

To investigate whether the responses given by the participants are affected by their profile, the values of Kruskal Wallis test are shown in table (3.15).

Table (3. 15): The Kruskal Wallis test for the end users' requirements.

The end users' requirements	Position	Experience	Sector
A user friendly interface to facilitate the usage and inputting needed information	0.026	0.392	0.176
A data bank contains samples of old project and varieties of facilities.	0.910	0.568	0.692
The ability to update the layout with the project progresses	0.037	0.146	0.241
A 3D representation for facilities and layouts	0.138	0.910	0.428
A detailed help menu	0.146	0.111	1.000
A dynamic modelling approach	0.111	0.438	0.294
Multi-objective function	0.922	0.333	0.176

Inspection of the table indicates that, for a level of significance of  $< 0.05$ , the participants' position has an effect on participants' responses "A user friendly interface to facilitate the usage and inputting needed information" and "The ability to update the layout with the project progresses". This may demonstrate that the

difference in position effects the way they specify the features and capabilities of automated systems. While for a level of significance of  $> 0.05$ , the participants' responses are not affected by their experience or sector.

#### SECTION IV – SITE LAYOUT PLANNING FACILITIES AND RELATIONS

This section seeks to specify the most repetitive temporary facilities in real construction sites with their sizes and relations. The participants are required to choose or add of the attached list, the most fourteen repetitive temporary facilities exist in construction sites with their approximate sizes. The attached list includes thirty-four places for the temporary facilities, which is divided to thirty-one places of the famous temporary facilities that could exist in construction sites that are prepared based on findings from literature review. In addition to three empty places, the participants are allowed to add any temporary facility that is not include in the list. The number fourteen is chosen based on findings from the literature review in chapter 2 to cover the limitation of existing in the number of facilities incorporated and personal sites visits which indicate its suitability for the most of projects. These facilities will choose based on their percentage of frequencies of the participations' responses. It is set originally to choose the facilities with percentage of frequencies more than 50 % but after calculating the percentage of frequencies for all the participations' responses, it is found that nine facilities only exceed this targeted percentage as shown in figure (3.19).

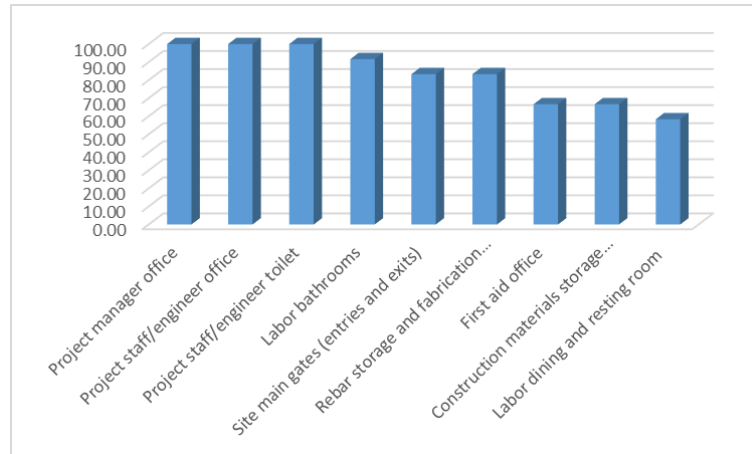


Figure (3. 19): The facilities with percentage of frequencies more than 50 %.

Therefore, to help achieve the targeted number of facilities and more global results, the Medium for the facilities percentage of frequencies is calculated as it expresses the middle value for the percentage of frequencies. The Medium is found to be 33.3 %, thus, the facilities with percentage of frequencies more than 33.3 % will be chosen. Figure (3.20) shows the facilities with percentage of frequencies more than 33.3 % to 50 %.

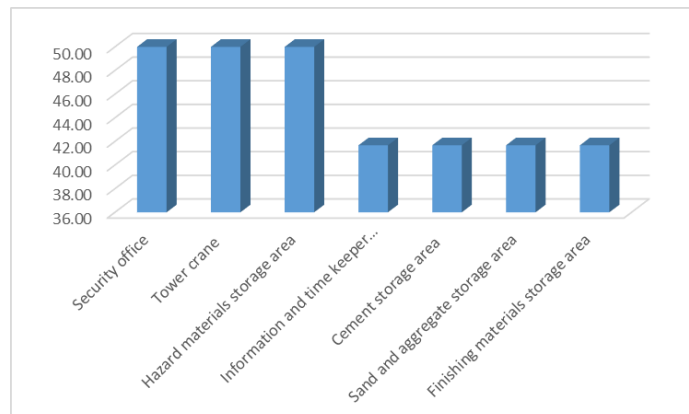


Figure (3. 20): The facilities with percentage of frequencies more than 33.3 % to 50 %.

Therefore, sixteen facilities will be chosen as shown in table (3.16) with the average sizes which calculated based on the participations' responses.

Table (3. 16): The sixteen chosen facilities with their sizes.

<b>No.</b>	<b>Facilities Names</b>	<b>Size (width*length*height) in meters</b>
1	Project manager office	5*6.5*3
2	Project staff/engineer office	8*10*3
3	Project staff/engineer toilet	3*4*3
4	Labor dining and resting room	13*12*3
5	Labor bathrooms	5*6*3
6	Security office	3*2*3
7	Information and time keeper office	2.5*3*3
8	First aid office	5*5*3
9	Site main gates (entries and exits)	12 m length
10	Tower crane	8*4
11	Cement storage area	13*6*3
12	Sand and aggregate storage area	26*24
13	Rebar storage and fabrication area	18*24*3
14	Construction materials storage area	18*40*3
15	Finishing materials storage area	5*5.5*3
16	Hazard materials storage area	12*20*3

Furthermore, the participants are required to specify the interrelation closeness weights between the facilities they choose, then with any virtual proposed building. The interrelation closeness weight reflects the closeness or distance between any pairs of facilities based on two optimization concern; 1) minimizing the travel cost/time and 2) maximizing safety. The protection of surrounding environment optimization concern is not included in this survey as it is not point of interest in the Egyptian sites as mentioned before in chapter 2. Specifying the interrelation closeness weights for minimizing the travel cost/time in construction sites will be based on six governing factors as below:



1. Equipment work flow (EF).
2. Material work flow (MF).
3. Personnel flow (PF).
4. Information flow (IF).
5. Time preference (TP).
6. User preference (UP).

After the choice of the sixteen facilities mentioned above, their interrelation closeness weights are calculated based on participations' responses Mode value. The Mode is chosen as it expresses the most repetitive value which is considered the real expression of the participations' responses. Whereas, the Mean expresses the average value which could be affected by any extreme value given by the participations therefore it will be considered as a fake expression of the participations' responses. Furthermore, the Maximum and Minimum express the limits' values which are considered as a fake expression of the participations' responses also. Therefore, the Mode values are chosen, however, the tables (3.17; 3.18; 3.19; 3.20; 3.21; 3.22 and 3.23) show the interrelation closeness value between the sixteen facilities based on the Mode values for both of the optimization concerns mentioned above.

#### A) The cost/time closeness relationship

1. Equipment work flow (EF).

Table (3. 17): The facilities cost/time closeness relationship based on the equipment work flow.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	5	5	9	8	5	5	7	8	0	0	1	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3	0	0	0	0	0	0	0	0	0	0	0	0	0			
4	0	0	0	0	0	0	0	0	0	0	0	0				
5	0	0	0	0	0	0	0	0	0	0	0					
6	0	0	0	1	1	1	1	0	0	0						
7	0	0	0	0	0	0	0	3	0							
8	0	1	0	0	4	0	1	0								
9	2	0	0	1	6	6	1									
10	0	0	0	0	3	5										
11	5	5	0	0	0											
12	5	0	0	0												
13	2	2	0													
14	2	3														
15	3															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

## 2. Material work flow (MF).

Table (3. 18): The facilities cost/time closeness relationship based on the material work flow.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	3	6	9	9	9	9	5	9	0	0	7	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
4	0	0	0	0	0	0	0	0	0	0	0	0				
5	0	0	0	0	0	0	0	0	0	0	0					
6	3	5	6	5	3	6	1	9	0	0						
7	0	5	0	0	3	0	0	4	0							
8	1	1	0	0	0	0	1	0								
9	2	4	4	9	8	8	0									
10	6	5	3	0	4	6										
11	1	5	0	0	0											
12	5	0	0	0												
13	6	4	0													
14	4	7														
15	6															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

### 3. Personnel flow (PF).

Table (3. 19): The facilities cost/time closeness relationship based on the personnel flow.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	6	5	6	6	5	5	1	5	6	8	4	7	7	7	9	9
1	0	0	0	0	5	5	0	0	0	2	4	0	0	0	9	
2	1	4	2	5	5	5	3	5	8	6	5	0	5	9		
3	0	0	0	0	0	0	0	0	1	2	0	0	0			
4	7	7	6	0	0	0	7	7	7	0	5	0				
5	2	2	4	0	0	0	1	0	1	0	0					
6	4	4	3	1	0	2	0	9	4	0						
7	2	0	0	0	0	0	0	4	4							
8	4	3	0	0	0	0	3	0								
9	3	5	5	7	7	7	0									
10	0	0	0	0	0	0										
11	6	5	1	0	0											
12	5	0	1	0												
13	3	3	3													
14	4	3														
15	5															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

### 4. Information flow (IF).

Table (3. 20): The facilities cost/time closeness relationship based on the information flow.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	4	4	5	1	1	1	0	0	2	9	7	0	0	0	9	9
1	9	9	9	0	3	3	0	9	9	9	9	0	0	0	9	
2	9	9	9	0	3	3	0	9	0	5	5	0	0	0		
3	0	0	0	0	0	0	0	0	0	0	0	0	0			
4	5	7	4	0	0	0	0	0	0	0	0	0	0			
5	0	0	0	0	0	0	0	0	0	0	0	0				
6	4	4	5	0	0	0	0	9	0	3						
7	7	3	0	0	0	0	0	3	0							
8	4	2	0	0	0	0	0	0								
9	6	6	6	0	0	0	0									
10	0	0	0	0	0	0										
11	5	5	1	1	1											
12	3	0	1	1												
13	4	3	0													
14	3	3														
15	4															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

##### 5. Time preference (TP).

Table (3. 21): The facilities cost/time closeness relationship based on the time preference.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	1	1	1	7	7	7	5	8	0	5	0	0	2	0	0	0
1	0	0	0	0	3	3	0	0	0	3	0	0	0	0	9	
2	0	0	0	0	3	3	0	0	0	0	0	0	0	0	9	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
4	0	0	0	0	0	0	0	0	0	0	4	0				
5	0	0	0	0	0	0	0	0	0	0	0					
6	0	5	4	0	4	4	4	9	0	0						
7	0	0	0	0	3	3	0	4	0							
8	0	0	0	0	0	0	0	0								
9	0	3	3	5	5	5	3									
10	2	3	1	0	0	6										
11	1	5	2	0	0											
12	4	5	2	0												
13	2	2	2													
14	0	3														
15	2															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

#### 6. User preference (UP).

Table (3. 22): The facilities cost/time closeness relationship based on the user preference.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	3	5	8	9	9	9	9	9	8	5	2	4	4	9	9	9
1	0	0	0	0	0	0	0	0	0	3	0	0	0	9	9	
2	0	0	0	0	0	0	0	0	0	3	1	0	0	9		
3	0	0	0	0	0	0	0	0	0	0	0	0	0			
4	0	0	0	0	0	0	0	0	0	5	0	9				
5	0	0	0	0	0	0	0	0	0	0	0	0				
6	2	2	2	1	4	4	3	7	0	0						
7	2	2	2	1	0	4	0	4	2							
8	0	0	0	0	6	3	0	0								
9	0	0	0	0	4	4	0									
10	6	6	6	9	0	5										
11	5	5	1	7	7											
12	5	0	1	7												
13	1	4	6													
14	0	8														
15	0															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible.

#### B) The safety closeness relationship

Table (3. 23): The facilities safety closeness relationship.

Facility number	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Proposed building	0	4	4	3	3	3	9	0	9	0	3	0	0	0	0	0
1	0	0	0	0	0	0	0	0	9	5	9	0	0	0	9	
2	0	0	0	0	0	0	0	0	9	9	9	0	0	0		
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
4	0	0	0	0	0	0	0	0	0	6	0	5	0			
5	0	0	0	0	0	0	0	0	7	0	9					
6	4	6	3	3	1	2	1	9	9	5						
7	0	6	0	0	0	0	0	4	6							
8	0	7	6	5	8	6	7	9								
9	0	0	0	0	0	0	0									
10	5	5	4	5	3	3										
11	0	5	3	3	5											
12	5	2	3	3												
13	5	5	5													
14	5	5														
15	6															

Zero means that the relationship between these two facilities is undesirable or no relation between them. While Nine means that the relationship between two facilities is as close as possible. The sixteen facilities with their sizes and relation will be incorporated in the proposed automated system as it will be discussed in chapter 6.

The analyzed data from returned questionnaires has benefited this research at the explicitness and precision of its research problem. These data identified the site layout planning importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning in real construction sites as discussed above. Furthermore, it will help in designing and developing the proposed automated system in chapter 6 with the finding from chapter 2. Especially, the end users' requirements which is consistent with the existing automated systems shortcomings and limitations that have been reached by this research in the literature review stage. Therefore, it must be taken into consideration in designing and developing the proposed automated site layout planning system. These findings create continuous pressures on this research to introduce new robust design that is capable to covering the aforementioned limitations

and shortcomings as well as offering the end users' requirements to improve the practicality of the proposed automated system in generating site layouts solutions. Furthermore, the underlying assumption of this research is to develop an automated system that can be adopted by construction industry. Therefore, this research will utilize the MATLAB<sup>®</sup> (The MathWorks Inc., MATLAB<sup>®</sup>, 2013a) program based on genetic algorithms toolbox for solving site layout planning problems to develop the proposed automated system, as they are the suitable tool and technique to overcome the site layout planning limitations and shortcomings as well as offering the end users' requirements. The following sections will introduce a review about the MATLAB program and the Genetic Algorithms optimization technique with their potential capabilities and suitability to overcome the site layout planning limitations and shortcomings as well as offering the end users' requirements.

### **3.4. TOOLS AND TECHNIQUES FOR THE PROPOSED AUTOMATED SYSTEM**

#### **3.4.1. MATLAB Theoretical Background, Capabilities and Suitability**

##### **A. MATLAB theoretical background and capabilities**

The name MATLAB stands for MATrix LABoratory. Cleve Moler, a numerical analyst, wrote the first version of MATLAB in the 1970s. Since then, it has evolved into a successful commercial software package (Griffiths, 2015). Originally, MATLAB was written to enable easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects (Houcque, 2005).

It is a language of high-level standard and interactive environment for numerical computation, visualization, and programming. It is capable of analyzing data, developing algorithms, and creating models and applications. In addition, a range of

applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance and computational biology can use it. Moreover, it can be used in projects such as modeling energy consumption to build smart power grids, developing control algorithms for hypersonic vehicles, analyzing weather data to visualize the track and intensity of hurricanes and running millions of simulations to pinpoint optimal dosing for antibiotics. It is used by a wide range of engineers and scientists in industry and academia as it is the language of technical computing (The MathWorks Inc.).

Furthermore, MATLAB is considered as a modern programming language environment as it includes some sophisticated data structures, contains built-in editing and debugging tools and supports object-oriented programming. Accordingly, MATLAB is an excellent tool for teaching and research. It has many advantages in comparison with conventional computer languages (e.g., C/ C++, Java®, FORTRAN) by its language, tools and built-in math functions which are capable of solving technical problems and reaching a solution faster. It is a system based on interaction whose basic data element is an array that does not require dimensioning. The software package has been commercially developed since 1984 and is now used as a standard tool at most universities and industries worldwide (Houcque, 2005).

It consists of strongly built-in routines that allow a very wide variety of computations; in addition to easy-to-use graphics commands that enable the visualization of results immediately available. It also has a toolbox that includes specific applications collected in packages, some of them are used for signaling processing, symbolic computation, controlling theory, simulation, optimization, graphics, visualization and several other fields of applied science and engineering (Figure 3.1) (Houcque, 2005; The MathWorks Inc.).



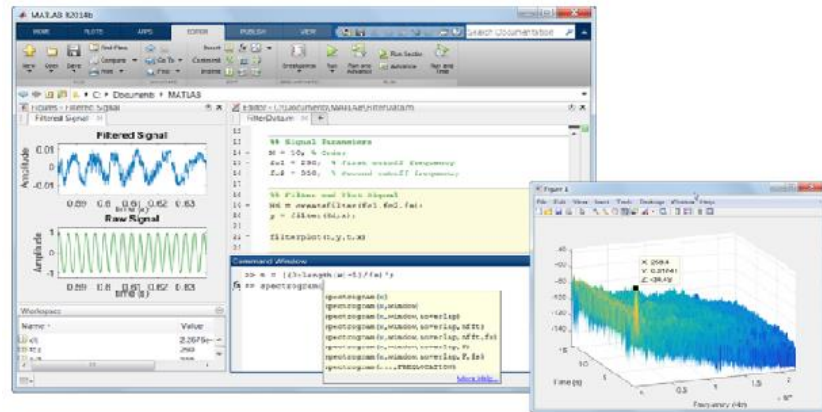


Figure (3. 21): Analyzing and visualizing data using the MATLAB (The MathWorks Inc.).

What is mentioned before provides only a brief glimpse of the power and flexibility of the MATLAB system. But MATLAB as a computer program is like any other computer programs has strength and weakness points. Strength points such as:

1. MATLAB exploits highly respected algorithms and so users can be confident about their own results.
2. MATLAB combines nicely calculation and graphic plotting.
3. MATLAB can import and export data from files, other applications, web services, and external devices.
4. MATLAB is relatively a learning-easy program.
5. MATLAB is interpreted (not compiled), errors are easily fixed.
6. MATLAB is optimized to performing matrix operations fast (Griffiths, 2015; Houcque, 2005).

Weakness points such as:

1. MATLAB is not considered as a general purpose programming language such as C, C++, or FORTRAN.
2. MATLAB is not suitable for other applications and it is primarily designed for scientific computing.
3. MATLAB is not as fast as a compiled language such as C++ as it is an interpreted language.
4. MATLAB commands are specific for MATLAB usage. Most of them do not have a direct equivalent with other programming language commands (Griffiths, 2015; Houcque, 2005).

#### B. MATLAB suitability

Although MATLAB has some weakness points but it does not influence the decision to adopt it to develop the proposed automated system. Because MATLAB offers characteristics and capabilities commensurate with what this research aims to achieve in designing the proposed automated system, MATLAB presents huge capabilities in solving and simulating complex problems like site layout planning problems. Firstly, it allows a native support in order to enable fast development and execution for the vector and matrix operations that are essential to such problems. Secondly, the MATLAB language allows programs written and algorithms to develop faster than with traditional languages. This is due to the fact that performing low-level administrative tasks are not needed like declaring variables, specifying data types and allocating memory. The need for for-loops is eliminated in most of the cases by the support for vector and matrix operations. Accordingly, the replacement of several lines of C or C++ code can be the result of one line of MATLAB. So the dynamic site layout problem characteristics could be easily handled by MATLAB as well as updated at any point of time.

In addition, MATLAB has a unique Optimization Toolbox™ provides widely used algorithms (including genetic algorithms toolbox which explains in detail in the next section) for standard and large-scale optimization. These algorithms are used to solve constrained and unconstrained continuous and discrete problems. The toolbox also includes functions for linear programming, quadratic programming, binary integer programming, nonlinear optimization, nonlinear least squares, systems of nonlinear equations and performs trade off analysis with balancing of multi objective optimization. This optimization toolbox fits with the planned multi objectives optimization engine, which will be developed in the proposed automated system to support the simultaneous optimization of construction objectives offered in this research.

MATLAB also offers the Graphical User Interface Development Environment (GUIDE), which enables the lay out, design, and edits custom graphical user interfaces. GUIDE includes common controls such as list boxes, pull-down menus, and push buttons, as well as MATLAB plots. Thus, by using the GUIDE a custom user friendly interface could be produced for the proposed automated system windows, which are a major demand by the field questionnaire participants. The user friendly interface will enable the user to work with system, input data and generate layouts in easy, organized and clear manner.

Another unique function available in MATLAB is the Data import and export functions that provide access to data from files, other applications, web services and external devices. Data import and export functions can read most of popular file formats, such as Microsoft Excel spreadsheets, text, images, audio and video, and scientific data formats. Low-level file I/O functions can work with data files in any format. This function will give the proposed automated system the ability to share,

import or export any project data fast and easy. Moreover, MATLAB provides built-in 2D and 3D plotting functions, as well as volume visualization functions. These functions can visualize the system results and plots can be customized either interactively or programmatically which give huge flexibility in representing these results.

Furthermore, a result report can be automatically generated when a MATLAB program is executed. Program code, comments and program results, including plots may be contained in this report. Reports can be formatted to share, meet publication specifications and saved to common graphical and data file formats (Figure 3.2).

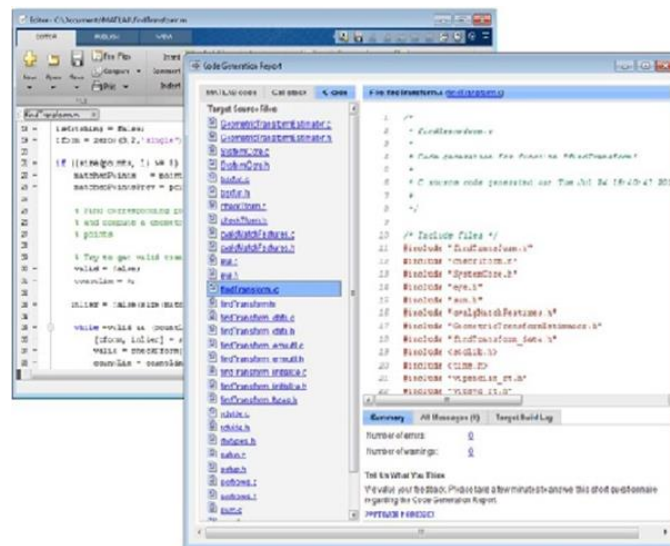


Figure (3. 22): MATLAB code (left) and code generation result report (right) (The MathWorks Inc.).

This is an important feature that makes the proposed automated system distinction in developing customized and clear result reports. Based on the foregoing, the MATLAB considers the most suitable program to develop the proposed automated system because it offers a lot of unique feature fit with the targeted goals of the system. Also the MATLAB capabilities will cover a lot of drawbacks and limitations of the

developed automated system as well as satisfy the major demand for the real life projects which identified by the field questionnaire participants.

### **3.4.2. Genetics Algorithms Theoretical Background, Capabilities and Suitability**

#### **A. Genetics Algorithms theoretical background and capabilities**

MATLAB can solve and simulate complex problems by its toolbox such as: (Numerical toolbox and Optimization toolbox). The optimization Toolbox™ provides widely used algorithms including genetic algorithms toolbox, the genetic algorithms will be utilized as the optimization algorithms to execute the optimization process in the multi objectives optimization engine, which will be developed in the proposed automated system.

The Genetic Algorithms is based on the phenomenon of natural selection that was defined by Charles Darwin (1929). Natural selection or survival of the fittest is the phenomenon that explains the death of the individuals who cannot bear the changes in the natural conditions and the survival of the individuals who can. The survived individuals must have certain genes that made them survive and so these genes can be maintained in the next generations by choosing the fittest individuals to be the parents of the next generations (Soremekun, 1997).

Genetic Algorithms belong to evolutionary algorithms which are devised from the mechanics of natural selection and genetics to search for the optimum solutions through decision space. Locating the globally optimal solution is done through the random but directed search that is generated by genetic algorithms (first generation), where each generation contains a predefined number of population size as shown in figure (3.3). This optimal solution is selected intelligently by genetic algorithms from the predefined number of generated solutions. A representation scheme is required for

genetic algorithm to encode feasible solutions for optimization problems. Usually, a linear string called chromosome is represented the solution, where each chromosome carries a certain number of genes and its length differentiates from one problem to another. The construction process for new solutions (generation) needs some measures of fitness (objective function) and constraints (Sanad et al., 2008).

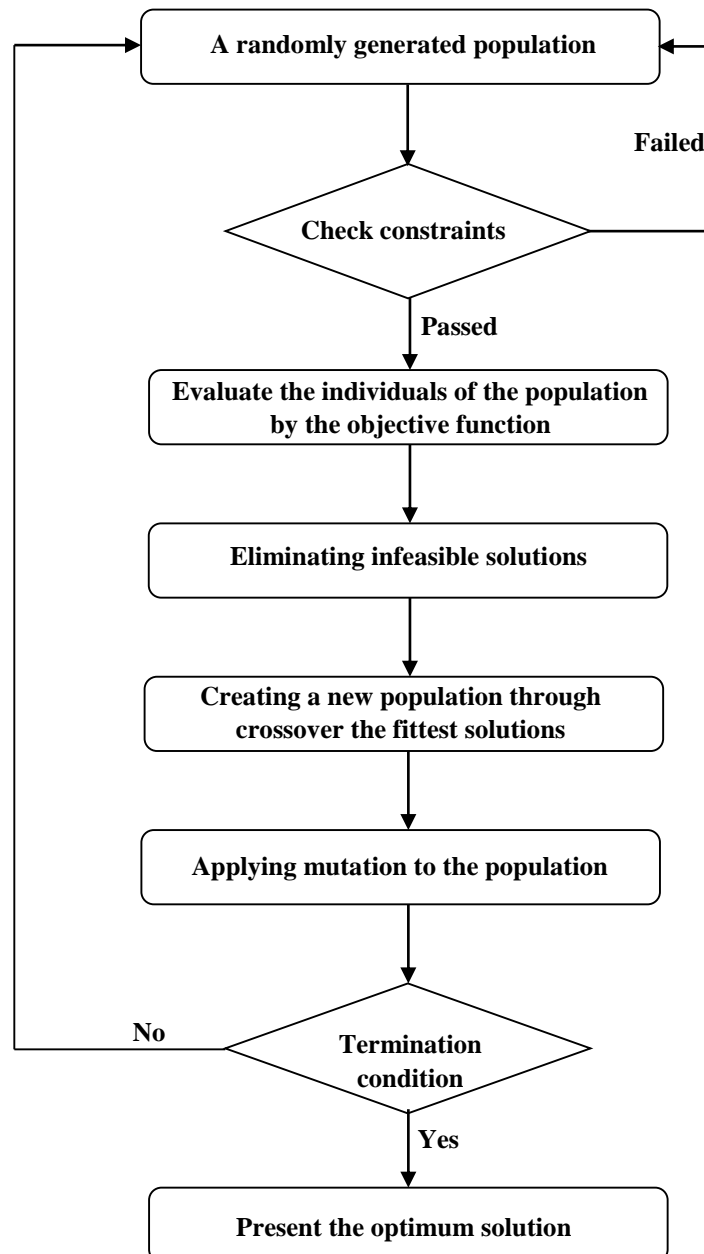


Figure (3. 23): Genetic Algorithms Flow Chart (Goldberg, 1989).

After the chromosome structure is formed and the objective function is set, the genetic algorithm evolutionary applications implementation on parent chromosomes are start. These applications include three genetic operations have to take place: Selection, crossover and mutation. Firstly, selection is the operation that differentiates between chromosomes with better fitness values and lower fitness values as the better ones survive for producing the new generation and others are eliminated. Secondly, the survived chromosomes are subjected to the crossover operation to combine and match their targeted qualities in a random process. This process is implemented by choosing two parent chromosomes, combining their qualities and producing offspring (crossover operation sometimes called marriage operation) (Jones, 2006). This information exchange can be achieved through a Double-Point crossover or single-point crossover between two parent chromosomes (Figure 3.4).

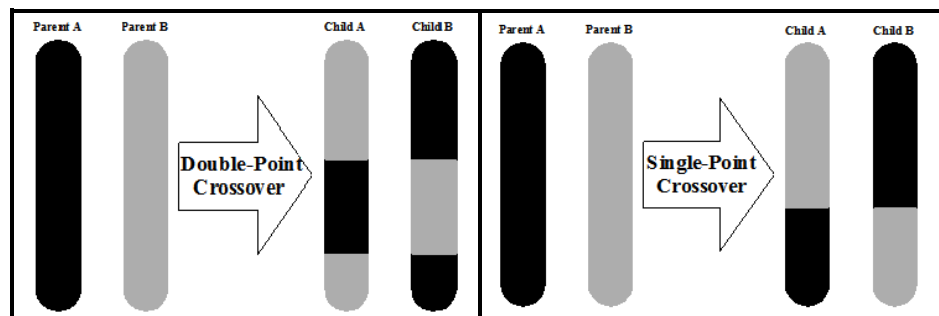


Figure (3. 24): Double-Point and single-point crossover (Jones, 2006).

Thirdly, Mutation is considered as an operation that represents an odd offspring sudden operation process that turns out to be genius (Goldberg, 1989; Sanad et al., 2008). The breaking of becoming stagnant in the evolutionary process and avoiding local optima trap are the benefits of the mutation process (Sanad et al., 2008).

The optimization process launched at initialization and can be iterated until termination condition has been achieved. The common termination conditions are one

or all of the following: 1) Fixed number of generation reached. 2) The generated solution satisfies the requirement of objective function. 3) The value of solutions or best-so-far solution fluctuates within a small defined range (Lam et al., 2009). However, the genetic algorithms parameters used to develop genetic algorithms optimization process must subject to tuning process to illustrate its effect on the performance of the genetic algorithms in generating optimal solutions. Chapter 6 will introduce the result of the tuning process executed on the genetic algorithms to achieve the best parameters that generate the optimal solutions.

#### B. Genetics Algorithms suitability

Research reveals that genetic algorithms are robust techniques and have the capability to be applied to a wide range of engineering and construction management problems (Elbeltagi et al., 2004). However, the findings of Wolpert and Macready (1997) must be put into consideration that there is no single algorithm that will perform well on all problems. In this research, because of their ease of implementation (Kumar & Cheng, 2015) and its ability to explore a search space (the space of all possible solutions), genetic algorithms are utilized as optimization algorithms. This is considered as a powerful feature for site layout planning problems. In addition, genetic algorithms have a huge ability to deal with inexact, missing, or poorly defined problems which fit the dynamic nature for construction site (El Ansary & Shalaby, 2014). Moreover, it is a very efficient optimization technique to perform multi objective optimization layout planning problems with the huge tradeoffs between the various objectives (Said & El-Rayes, 2013).

Furthermore, local and global search techniques are two classifications that are available for optimization techniques to solve general optimization problems. Local



optimization techniques are classified as local minimize in nature as they begin the search procedure with a guess solution that is often chosen randomly in the search space. However, there is a drawback of these techniques like if the guess solution is not choosing close enough to the global mini-mum solution, the result is that the optimization technique will be trapped in a local minimum. Estimating the location of the guess solution, in the site layout problems, is not an easy task. In addition, due to the intersection of the constraints with the objective function, multiple optima are expected (El Ansary & Shalaby, 2014). That is why global search optimization techniques such as genetic algorithms (GAs) are found to be quite promising global optimizers for the site layout problem undertaken in this research.

### **3.5. SUMMARY AND CONCLUSIONS**

The main concern of this chapter was to assess the site layout planning in the real Egyptian construction sites for more clearly formulate an explicit and precise research problem and setting the proposed automated site layout planning system tool and technique. The conclusions drawn from this chapter are summarised below:

- The population sample confirmed the importance of the site layout planning task as any other projects' task.
- The efficient site layout planning could multiple projects' objectives such as minimizing cost and time, maximizing safety and protecting the surrounding environment. However, responses given by the sample generally indicated that the real construction sites interest in minimizing the projects' cost and time and maximizing the projects' safety more than protecting the projects' surrounding environment.

- The most appropriate stage – of the project’s life cycle –for implementing of the site layout planning task is the planning stage.
- The quality of the site layout plan is affected by the stage it is implemented in.
- Responses given by the sample indicated that the most suitable person to execute the site layout planning task is the project manager.
- The information needed to develop a site layout plan in real sites are the project schedule, site boundary and drawings, needed facilities, project size and project budget.
- The high scores given to determining the temporary facilities location stage as the most difficult stage in implementing the site layout planning.
- Responses given by the sample indicated that the site layout plan need to be updated with the project’s duration.
- Inefficient site layouts planning may lead to problems in construction sites which impact negatively on the projects performance.
- The highest proportion of participants did not use an automated site layout planning systems before. However, they also were supportive to such systems as they thought it will help in developing more efficient site layouts.
- The Egyptian sites end users’ requirements which needed to offer in any new automated system are:
  1. a user friendly interface to facilitate the usage and inputting needed information.
  2. a data bank contains samples of old project and varieties of facilities.
  3. the ability to update the layout with the project progresses.
  4. a 3D representation for facilities and layouts.
  5. a detailed help menu.

6. a dynamic modelling approach.
  7. multi-objective function.
- MATrix LABoratory (MATLAB) and Genetic Algorithm (GA) are considered the suitable tool and technique to overcome the site layout planning limitations and shortcomings as well as offer the end users' requirements.

The next chapter will present the design of the research methodology adopted in this research.

## **CHAPTER 4**

### **RESEARCH METHODOLOGY**

#### **4.1. INTRODUCTION**

The literature reviews in Chapters 2 and 3 suggested the development of an automated dynamic site layout planning system that gives a better solution to a relevant problem faced by practitioners of construction industry which is the site layout planning. The aim of this chapter is to describe the methodology to research the validity of these aspects and provides justification for their use along with the tools utilized. The chapter, first, presents the research design based on the research type and aim. It, then, discusses the chosen research methodology, design science and explains why design science methodology best suits to this research. This chapter also discusses the research philosophies and approaches, then it reviews the available research strategies. The data collection' and analysis' methods and the methodological approach of the research are also presented in this chapter. The methodological approach follows the design science cycle; however, it is grouped as three stages: pre-development, development and post-development.

#### **4.2. RESEARCH DESIGN**

This research methodology design will be presented based on the research type and aim. The research undertaken for this thesis is an Information Technology (IT) research aims to develop an automated dynamic site layout planning system for construction sites, based on Genetic Algorithms (GA) as optimization engine. Thus, this is the developmental and technological IT research – aims to develop an artifact that gives a solution to an important and relevant problem which is the site layout planning – that requires an appropriate research methodology model. The design

science methodology comprehends the importance of IT research as a vital item of improving and developing artefacts to produce better solutions (Vaishnavi & Kuechler, 2007). Therefore, the design science research methodology will be used as the main figure of explaining this research methodology design. The next paragraphs will explain the research type, aim and the design science research methodology in detail and justifies the selection of this methodology.

This research aims to develop a computer program that gives a better solution to a relevant problem faced by practitioners of construction industry. Therefore, this research is considering an IT research because it addresses the real problem faced by construction industry practitioners and utilizes technology to acquire and process information in solving it to support a human purpose IT pervasive nature is spread all over the industrialized world. Millions of dollars are spent annually by business and government organizations to develop and maintain such IT systems as they affect our work and how that work is done (Scott-Morton, 1990). Significant improvements are the result of some innovative uses of information technologies for some companies and have created the competitive marketplace for others (March & Smith, 1995).

The main concern of IT practice is the development, implementation, operation and maintenance of IT systems (Madnick, 1992). It has some great scientific attention because of its positive and negative impact on organizations. Furthermore, the pervasiveness of IT phenomena in our information-based society have been attracted scientists (Drucker, 1988, 1991). Scientific theories can explain the phenomena of IT and that scientific research can improve IT practice. The descriptive and prescriptive approaches are the two kinds of scientific interest in IT. The former aims at understanding the nature of IT; in other words, it is a knowledge producing activity related to natural science (March & Smith, 1995). While the latter aims at improving

IT performance. To put it differently, it is a knowledge that uses the activity related to design science (Simon, 1981).

This differentiation has created a dichotomy among IT researchers and over what constitutes legitimate scientific research in the field. These disapprovals exist naturally in fields that have both knowledge-producing and knowledge-using activities. They are promoted by the belief attached to science in modern societies and the belief that the term "science" has to do with the production of theoretical knowledge. Such debate in IT research is equal to that between engineering and the physical sciences. It is normal that Knowledge-producing, "pure" science is the winner in such debates; however, the situation is different in IT. It could be argued that developing IT systems and improving IT practice aimed by any research are more success and importance than traditional scientific efforts to understand it (March & Smith, 1995).

IT research studies are artificial in contrast with natural phenomena as it has to do with human creations like organizations and information systems. These have prominent implications for IT research. Of immediate interest is the fact that artificial phenomena can be both created and studied, and that scientists can contribute to each of these activities. This underlies the dual nature of IT research. Rather than being in conflict; however, both activities can be encompassed under a broad notion of science that includes two distinct species, termed natural and design science (Simon, 1981). Natural science is concerned with explaining how and why things are. Design science is concerned with "devising artifacts to attain goals" (Simon, 1981).

Natural science includes traditional research in physical, biological, social, and behavioral domains. Such research is aimed at understanding reality. Natural scientists develop sets of concepts, or specialized language, with which to characterize

phenomena. These are used in higher order constructions - laws, models, and theories - that make claims about the nature of reality. Theories - deep, principled explanations of phenomena - are the crowning achievements of natural science research (March & Smith, 1995). Products of natural science research are evaluated against norms of truth, or explanatory power. Claims must be consistent with observed facts, the ability to predict future observations being a mark of explanatory success. Progress is achieved as new theories provide deeper, more encompassing, and more accurate explanations.

Natural science is often viewed as consisting of two activities, discovery and justification (March & Smith, 1995). Discovery is the process of generating or proposing scientific claims (e.g., theories, laws). Justification includes activities by which such claims are tested for validity.

The aim of natural science is understanding reality. Whereas, The aim of design science is to create things for the benefit of human purposes. In other words, it is technology-oriented; its products are assessed against criteria of value or utility - does it work? Is it an improvement? Design plays a vital role in fields like architecture, engineering and urban planning that may not be thought of as "sciences" per se (Schon, 1993). Typically, design activities are a core element of traditional scientific fields, some scientists conduct both natural and design science investigations. Similarly, fields like operations research and management science (OR/MS) are conducted prescriptively, while claiming to be science. Design scientists try to create effective artefacts by producing and applying knowledge of tasks or situations. However, science is an activity that produces "credentialed knowledge" (Mishra & Eich, 1992). While for Simon (1981) design science is an significant part of it.

Design science is comprised of two basic elements build and evaluate which parallel the discovery justification pair from natural science. Building is the process of building an artifact for a certain purpose, while, evaluation has to do with the performance of the artifact (Johannesson & Perjons, 2012).

There is a difference between basic and applied science and it is also relevant; this reflects how closely scientific research impinges on practice. While natural science has to do with the basic research and design science has to do with applied, the two concepts are not strictly parallel. That is because a natural science account of information systems failure could be more relevant to practice than the development of a new data modeling formalism. However, the former is natural science research and the latter is a design science research. Repeatedly, research intent is critical (March & Smith, 1995).

This is similar to the difference between description and prescription frequently employed by decision scientists (Bell & Raiffa, 1988). Adding to that, natural science is descriptive and explanatory in intent and design science offers prescriptions and creates artifacts that embody those prescriptions. Natural science gives the explanations of how or why an artifact works, but that may lag years behind the application of the artifact. Accordingly, design science offers substantive tests of the claims of natural science research (March & Smith, 1995).

Van Aken (2004) describes the mission of the design science is to utilize in the improvement of the performance of existing entities to solve improvement problems, or to develop knowledge for the design and realization to solve construction problems.



While, Johannesson and Perjons (2012) presented the design science as a field of science to carry out the IT research by producing and communicating knowledge and define it as:

*“scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest”.*

Furthermore, Koskela and Ballard (2012) describes the natural and social science as explanatory and descriptive research on a part of the world, while design science (constructive research) is described as prescriptive research to create something new to the world. The outcomes of the design science (constructive research) could be artifacts (constructs (concepts), models, methods or instantiations (implementation)) (Hevner, Ram, March, & Park, 2004), better theories (Vaishnavi & Kuechler, 2007) or improvements (Van Aken, 2005).

From another side, this research aims to give a better solution to the site layout planning problem which is an important task of the construction projects management and economics (CPME). In the research field of CPME, the output of any research undertaken consists of contributions from different scientific disciplines because there are a lot of different topics to study. This results in a multidisciplinary characteristic of construction projects management and economics knowledge (Voordijk, 2009). This considers parallel to the characteristics of design since research methodology which are multidisciplinary and aims to solve complex and relevant problems in field. Such characteristic proves that the main objective of construction projects management and economics knowledge is to advance design solutions for complex and relevant field problems in the specific context of the design, production and operation of the built environment (Voordijk, 2009). This opposes to be an explanatory

science that only aims to develop knowledge by describing, explaining and possibly predicting (Van Aken, 2005).

It is interesting to know that much of the academic research in construction projects management and economics are developed with the approach of descriptive knowledge production (Voordijk, 2009). This approach is a theory-driven with a core mission to develop valid knowledge by understanding the natural or social world, or more specifically -describing, explaining, possibly predicting and producing shared understanding (Van Aken, 2005). However, the epistemological characteristics of construction management projects and economics research such as context of application, transdisciplinary, diversity of the sites, highly reflexive and quality control (Nowotny, Scott, & Gibbons, 2003) are incompatible with the descriptive approach (Voordijk, 2009).

Whereas, The improvement of construction projects management and economics may occur if it would also include prescriptive or solution-oriented knowledge where the result from scientific justification (predicting, understanding or explaining phenomena) can be utilized in designing solutions to complex and relevant field problems. Developing prescriptive knowledge is rather field-problem driven and solution oriented. Its core mission to develop knowledge that can be used by professionals in the field in question is to design solutions to their field problem by describing and analyzing alternative courses of action in dealing with field problems (March & Smith, 1995).

Therefore, design science is suggested to be used to cover this gap due to the type of characteristic and the problem on how to tackle the issue of methodological underpinnings of CPME which have been debated in large number of academic

publications (Rooke, Seymour, & Crook, 1997; Runeson, 1997; Seymour, Crook, & Rooke, 1998; Voordijk, 2009). As the site layout planning – focus of this research – is considered as one of the tasks of construction projects management and economics, the argument of the design science methodology is pertinent for its research activities.

According to AlSehaimi, Koskela, and Tzortzopoulos (2012), the design science research can assist in the development and implementation of innovative managerial tools, tackling different managerial problems of construction. The same authors further argue that in so doing, design science research (constructive research) will better connect research and practice, and thus strengthen the relevance of academic construction management. Moreover, Koskela (2008) argues that repositioning construction projects management and economics as a design science rather than an explanatory science will help to solve problems affecting this discipline such as the problem of relevance.

Simon (1996)'s quotation below supports the argument that design sciences is relevant for research in organization and management.

*“Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artefacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a new state”.*

The history of the design science shows that it has some of its roots in management accounting and a closely related (Piirainen & Gonzalez, 2014) to a research method called “constructive research” which have been used two decades ago (Kasanen, Lukka, & Siitonen, 1993). Until now, constructive research (design science) has been

widely used and provide an established approach in the area of management accounting. Saunders, Lewis, and Thornhill (2009) presented the design science research from the design science perspective as developing a valid knowledge to support and solve field problem. As that the practice of site layout planning in construction projects is considered similar to accounting practice (art of organizing, maintaining, recording and analysing financial activities), design science can be considered relevant as a research methodology.

Based on the previous explanations of the research type, aim and the design science methodology, it is justified that the design science methodology is the most appropriate methodology for this research. The selection of this methodology is supported by (Kehily & Underwood, 2015) conclusion which resonate the design science methodology with the research with a view to affect change in a practical setting, which is suited with the aim of this research. Furthermore, Vaishnavi and Kuechler (2007) argue the reason that design science research is applicable to IT research (same type of this research) is due to some of the types of research problems that occur naturally in the field (same type of this research problem) which confirm the choice of this methodology.

One final note, the research design definition of a research shows a difference inside and between methodologies. In one research, the research design can mirror the complete research process, from conceptualizing a research problem to review the literature, techniques and conclusions, while in another research, the design might just refer to the methodology of the research (e.g., data gathering and analysis). In this research, the research design will define as the method that demonstrates the complete research process. Therefore, this research excludes the traditional academic research methodologies such as Nested Research (Kagioglou, Cooper, Aouad, & Sexton, 2000)

and Ring Onion (Saunders, Lewis, & Thornhill, 2003) and chooses the design science methodology. Because the research methodologies literature review reveals that the practical design science methodology is the most appropriate methodology for the research design definition in this research. The design science methodology can facilitate the complete research process by outlining a cyclical development and evaluation process which can firstly outline an issue in the environment; propose that a new process or technology could solve this issue and subsequently evaluate if the new solution is successful for its intended users and in its intended environment. The next sections will introduce the explanation to the philosophical grounding of this research (Kehily & Underwood, 2015).

### **4.3. RESEARCH PHILOSOPHY**

Research philosophy has to do with developing knowledge and the nature of that knowledge (Saunders, Lewis, & Thornhill, 2007). Research studies have different positions on the nature of research philosophy (Easterby-Smith, Thorpe, & Lowe, 2002). The three main philosophical positions epistemology, ontology and axiology are defined in the following paragraphs.

- ***Epistemology*** is the study that explores the nature of knowledge. It has to do with the constitution of acceptable knowledge in a certain field of study (Saunders et al., 2007).
- ***Ontology*** is the study that describes the nature of reality. It has to do with the researchers' assumptions on the operation way of the world around him (Saunders et al., 2007).

• **Axiology** is about study of values. It is concerned with the researchers' judgments about the values in order to prove its effectiveness in the stages of the research process (Saunders et al., 2007).

Research philosophy has some important assumptions on the researcher's viewpoint of the world. Particularly, these assumptions have to do with the researcher's view on the relationship between knowledge and its development process. Table (4.1) compares philosophical assumptions of the two most distinguished research paradigms for the different philosophical positions (Vaishnavi & Kuechler, 2007).

Table (4. 1): Different philosophical assumptions of major research paradigms (Vaishnavi & Kuechler, 2007).

<b>Basic Beliefs</b>	<b>Positivist</b>	<b>Interpretive</b>
<b>Ontology</b> - What is the nature of reality?	Single reality; knowable with probability	Multiple socially constructed realities
<b>Epistemology</b> - What is the nature of knowledge?	Objectively is important; researcher manipulates and observes in objective manner	Interactive link between researcher and participants; values are made explicit; created findings
<b>Methodology</b> - What is the approach for obtaining the desired knowledge?	Observation; quantitative, statistical	Participation; qualitative, Hermeneutical, dialectical
<b>Axiology</b> - What is of value?	Truth: universal and beautiful; prediction	Understanding: situated and description

Although the line between positivism and interpretivism is clear at a philosophical level, Easterby-Smith et al. (2002) argues that this line may become blurred at a research design level when the researcher needs to understand the real situation from

several perspectives. The researcher may decide to combine the way to obtain data using both ways: qualitative and quantitative to comprehend the nature of the real world as perceived by those interviewed and/or surveyed which mean combining of both paradigms which is suited for the purpose of this research.

Furthermore, in design science, just as in many other fields of science, both the positivist and interpretivist paradigm can be applied. It is even possible, indeed common, to make use of both paradigms in the same design science research (Johannesson & Perjons, 2012) which is more suited for the purpose of this research that has been designed based on design science. Therefore, during problem explication and requirements definition positivist methods chosen in order to obtain a deep understanding of the needs and desires of stakeholders as it will be discussed in section 4.6. This understanding will help to design and develop an artefact that is highly relevant for the stakeholders. For more validation and evaluation value rigour, positivist methods like surveys and experiments chosen in order to arrive at objectively valid results. Furthermore, interpretivist methods also chosen for evaluation in order to obtain a better understanding to the subjective experiences of users as it will be discussed in section 4.6.

Accordingly, the three main philosophical positions epistemology, ontology and axiology of the research philosophy are introduced in the following paragraphs from the point of view of the design science researcher.

Epistemologically, the design science researcher comprehends that a piece of information is factual and knows further the meaning of that information through the steps of construction. When the artifact is structured, its behavior will be the result of interactions between components. Descriptions of the interactions are information-

oriented and the degree in which the artifact behaves predictably, the information is true (Vaishnavi & Kuechler, 2007).

Ontologically, the design science researchers are comfortable with alternative world-states (Vaishnavi & Kuechler, 2007). However, the multiple world-states of the design science researcher are not the same as the multiple realities of the interpretive researcher: many if not most design science researchers believe in a single, stable underlying physical reality that constrains the multiplicity of world-states (Gregg, Kulkarni, & Vinze, 2001).

Axiologically, the design science researcher values creative manipulation and control of the automated system are valued by the design science researcher values. In addition, more traditional research values such as the pursuit of truth or understanding of the performance of the system. (Vaishnavi & Kuechler, 2007).

#### **4.4. RESEARCH APPROCH**

This research has chosen the design science as its research methodology. The important thing needs to be aware of that choice, how it will affect the later findings. Accordingly, this research has the ability to choose informally the strategies, approaches and methods that are suitable to it. It also has the ability to justify these choices. This research philosophical approach will follow the design science research process cycle for discovering, identifying and capturing problems and requirements of the site layout planning in construction industry and directly developing new and improved automated system to cover those problems and requirements. Therefore, it will be able to establish a link to the theoretical explanation at the end of the process. The explanation and justification to follow design science research process cycle as



the philosophical approach for this research is based on discussions in the following paragraphs.

Design science research is a philosophical approach that is used to produce innovative construction with the intention to solve problems faced in the real world. That means, it make a contribution to the theory of the discipline in which it is applied (Lukka, 2003). In addition, March and Smith (1995) classifies it as an approach that seeks to investigate new solution alternatives to solve problems, to clarify this exploratory process and to promote the problem-solving process and serve human purposes. (Rocha, Formoso, Tzortzopoulos-Fazenda, Koskela, & Tezel, 2012) considers the design science research or constructive research as an approach for conducting research in lean construction, and more specifically in construction projects management and economics. A design science research is not concerned with action itself, but with knowledge to be used in designing solutions, to be followed by design-based action (Van Aken, 2004).

The first important characteristic of the design science research is problem-solving. Secondly, the prescriptive nature of the outcome of a research program is another distinguishing characteristic. Lukka (2003) enrolls the design science research (constructive research) approach characteristics as:

- Real world problems are focused on to be solved in practice.
- An innovative construction is produced to solve the initial real world problems.
- An attempt for implementing the developed construction is included and thereby a test for its practical applicability.
- A very close involvement and cooperation are implied between the researcher and practitioners in a team-like manner.

- Is explicitly linked to prior theoretical knowledge.
- Pays particular attention to reflecting the empirical findings back to theory.

A core guideline for the design science research criteria as conceived in the design science research literature to set a framework for a research methodological approach is presented in table (4.2).

Table (4. 2): Guidelines for design science research criteria (Hevner et al., 2004; Venable, 2015).

<b>Criterion</b>	<b>Description</b>
<b>Identifiable contribution</b>	<p>Present an identifiable and viable design artifact.</p> <p>One or more clearly defined new concept, model, new way for building an artifact, or a method.</p> <p>One or more exemplary or expository instantiation (-s) of the artifact.</p> <p>Identify the novelty, significance and generalizability of the contribution explicitly.</p>
<b>Relevance</b>	<p>Address an important and relevant business problem (or a class of problems).</p> <p>Develop the artifact by an iterative search for available means to attain the ends under the constraints of the problem and environment.</p> <p>Address both academic rigor and relevance for professional audience.</p>
<b>Rigor</b>	<p>Evaluate the utility, quality and efficacy of the design artifact</p> <p>Apply rigorous, state-of-the-art, methodology to construction and evaluation of the design artifact.</p>

The connection between relevance (the context of design) and rigor (the business/environment) and the scientific knowledge base built by previous research is illustrated in three related cycles of activity as described in figure (4.1). These cycles are:

- First, the relevance cycle links the environment with design, sets the problem space, and informing design with the associated requirements and constraints, and later in the process instantiating the artifact and disseminating the results.
- Second, the design cycle comprises the internal design process of design science research, where the problem space and solution space interface and an artifact is synthesized and evaluated until it satisfies the criteria set for the design.
- Third, the rigor cycle links design science research and the scientific knowledge base, informs the solution space and contributing back to knowledge based on the evaluation (Fallman, 2008).

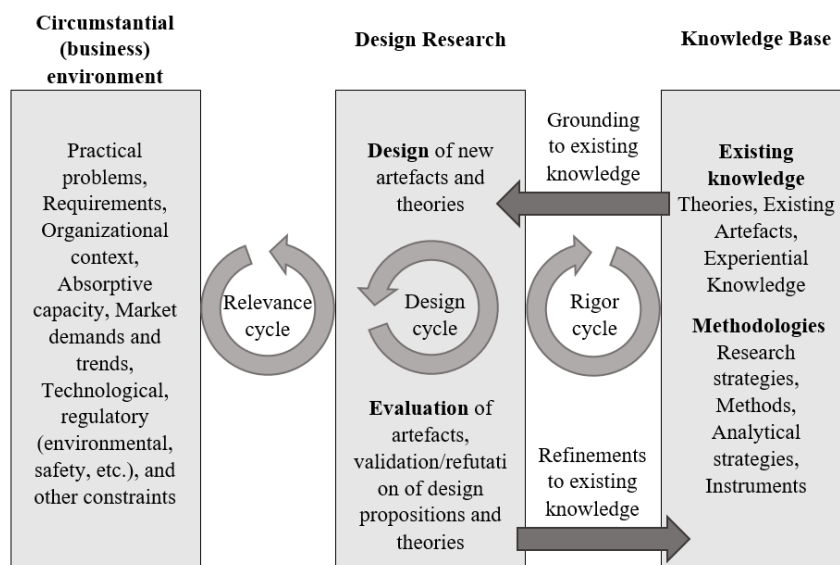


Figure (4. 1): Design science research cycles (Cash & Piirainen, 2015; Hevner, 2007).

During the design science research process cycle, design problems, requirements and constraint to the process are fed by the relevance cycle and carries the output of design to the environment. Whereas a secondary relevance cycle is found while the design is tested, demonstrated and refined in the design cycle. Both the rigor cycle and relevance cycle are interfaced by the design cycle, as the rigor cycle feeds the design with theory and the evaluation with methodology, and with the relevance cycle as the artifact is piloted and evaluated. Afterwards, the rigor cycle feeds the principles of form and function to the design and feeds the findings of evaluation of the artifact back to the knowledge base. However, the relationship between the three cycles can vary depending on the design problem and solution, and the methodological design of a design science research (Piirainen, 2016).

Based on the explanation and justification of the design science research process cycle characteristics mentioned above, this research will utilize the design science research process cycle as its philosophical approach. There are many models of the design science research process cycle such as Hevner (2007); Jarvinen (2004); Kasanen et al. (1993); Lukka (2003); March and Smith (1995); Peffers, Tuunanen, Rothenberger, and Chatterjee (2007); Vaishnavi and Kuechler (2004). However, this research has chosen to work around the research process proposed by Vaishnavi and Kuechler (2004) as shown in figure (4.2). The reason behind this choice is because the Vaishnavi and Kuechler (2004) model is considered the contribution of new and true knowledge as a key focus of design science research. Furthermore, it can be interpreted as an elaboration of the three design science cycles.

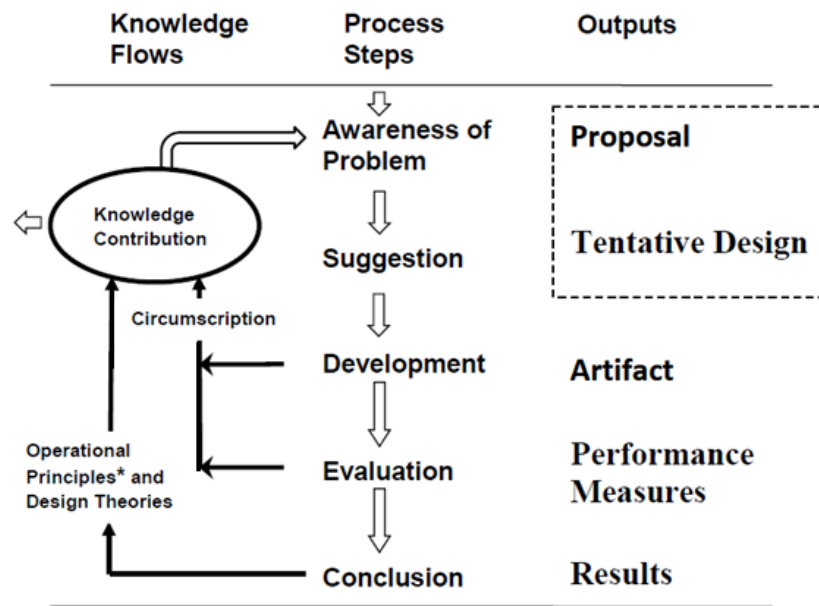


Figure (4. 2): Design Science Research Process Cycle (Vaishnavi & Kuechler, 2004).

In this model, all the design begins with being aware of a problem which may come from multiple sources including new developments in industry or in a reference discipline. Design science research or improvement research emphasizes the problem-solving or performance improving nature of the activity (Vaishnavi & Kuechler, 2007). Suggestions for a problem-solution are abductively drawn from the existing knowledge or theory base for the problem area (Pierce, 1931, cited in Vaishnavi and Kuechler, 2007). Implementing an artifact is suggest achieved in terms of development through partial or full success implementations are then evaluated based on to the functional specification implicit or explicit in the suggestion. In the course of the design research, the development, evaluation and further suggestions are often iteratively performed. The circumscription arrow indicates the base of the iteration and the flow from partial completion of the cycle back to awareness of problem. Finally, conclusion shows the end of the project (Vaishnavi & Kuechler, 2004). As mentioned before, this research follows the design science research process cycle as

its approach in order to develop the proposed automated system. However, this research will formulate the design science research process cycle into three main stages which are the pre-development stage, the development stage and the post-development stage to utilize them as its methodological approach. Therefore, the methodological approach as these stages to achieve the aim of this research are further described in section 4.7.

#### **4.5. RESEARCH STRATEGIES**

The purpose of design science is not only to create artifacts but also to answer knowledge questions about them and their contexts. In order to ensure that the knowledge produced is valid and reliable, it is a well established practice to make use of research strategies. The research strategy is the general set-up of the context in which the research is carried out. Within the design science research, it is possible to use any research strategy to answer knowledge questions about artefacts. In other words, no research strategies can be excluded in advance for a design science research, as any of them can be valuable depending on the characteristics and goals of the research (Johannesson & Perjons, 2012). Some of the well established research strategies that might be used in the design science research are introduced in the table (4.3).

According to Yin (2003), a research study could use more than one strategy and that each strategy must be suitable in specific conditions. Furthermore, Johannesson and Perjons (2012) state that it is common to use several research strategies in design science research, since the design approach steps can require different strategies which is suited for this research.

Table (4. 3): Relevance research strategies (Johannesson & Perjons, 2012).

<b>Surveys</b>	data collection from a large group of objects (people, organisations, systems, etc.) in order to find generalizations.
<b>Action research</b>	changing into a real environment in order to study and reflect on the effects of this change.
<b>Grounded theory</b>	data collection from the object of research then identify patterns or structures in this collected data, which will be the base for creating a theory.
<b>Experiments</b>	creating an artificial environment in order to isolate and study a small number of objects, thereby preventing other objects from influencing those under investigation to establishing cause and effect relationships.
<b>Case studies</b>	investigation in detail one specific case of the general phenomenon (an object or situation) in order to paint a rich picture of a single object or situation to be used as a basis for obtaining a deep and comprehensive understanding of some general phenomenon.
<b>Ethnography</b>	understanding the culture and perspectives of some group of people during a certain time in order to understand their actions.

Therefore, this research is designed to use grounded theory and survey strategies for the first stage of its methodological approach which is the pre-development stage. Grounded theory strategy is utilized to explicate the research problem in order to more clearly formulate a precise problem. The explication of the research problem is

performed mainly based on domain knowledge from the foundation. Grounded theory strategy chosen as Myers (2004) argues that grounded theory has gained growing acceptance in IT research because it is a very effective way of developing context-based, process-oriented explanations of the phenomena being studied which is suited for the purpose of this stage of research.

While, survey strategy is used to address the problem and specified its desirable features. In other words, it will be used to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real construction sites. Surveys strategy is chosen as it operates on statistical sampling, which chooses a representative sample from a population which is suited for the purpose of this stage of research (Fellows & Liu, 2003). The considerations for the survey and the targeted participants sample will be discussed in section 4.6. However, the sample used in this survey was targeting different positions of the construction industry practitioners with experience more than fifteen years of working on Egyptian sites as Egypt is the case study for this research.

The output from this stage will guide the development of the proposed automated system in stage two which is the development stage. Furthermore, the requirements will form the basis for the evaluation of the proposed automated system in stage three which is the post-development stage.

According to the third stage of this research methodological approach which is the post-development stage, it includes two processes: validation and evaluation of the proposed automated system as discussed further in section 4.7. The choice of validation and evaluation strategies can vary depend on the designed artifact and the



selected validation and evaluation metrics. Thus, the summary of the available design validation and evaluation strategies of artifacts is given in table (4.4).

Table (4. 4): Design Validation and Evaluation Strategies (Hevner et al., 2004).

<b>1. Observational</b>	Case Study – Study artefact in depth in business environment.
	Field Study – Monitor use of artefact in multiple projects.
<b>2. Analytical</b>	Static Analysis – Examine structure of artefact for static qualities (e.g., complexity).
	Architecture Analysis – Study fit of artefact into technical IS architecture.
	Optimization – Demonstrate inherent optimal properties of artefact or provide optimality bounds on artefact behavior.
	Dynamic Analysis – Study artefact in use for dynamic qualities (e.g., performance).
<b>3. Experimental</b>	Controlled Experiment – Study artefact in controlled environment for qualities (e.g., usability).
	Simulation – Executive artefact with artificial data.
<b>4. Testing</b>	Functional (Black Box) Testing – Perform functional test to discover failures and identify defects.
	Structural (White Box) Testing – Perform coverage testing of some metric (e.g., interfaces and execution paths) in the artefact implementation.
<b>5. Descriptive</b>	Informed Argument – Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility.
	Scenarios – Construct detailed Scenarios around the artefact to demonstrate its utility.

Therefore, this research will design to use experimental strategy in terms of simulation for the validation process to examine the proposed automated system accuracy and effectiveness. A simulation is chosen as it is an example of strategies that can be

employed to determine the potential effects of an artifact in the real-world environment. Simulation is exposing the artifact systematically to a simulated environment to experimentally assess its (potential) utility. Simulation could be conducted through field testing, lab testing or potential user assessments. However, the results of the validation process are expected to bring up defects or shortcomings that can be corrected by iterating back to the design cycle process. The simulation results may be used to measure artifact performance and compare it with the results of existing artifacts or the current situation in the real-world environment. In this case, the artifact inputs are taken from the simulation and the outputs compared to historical data in order to empirically determine its ability to behave according to the proposed hypothetical expectations (Manuel, 2012). In this research, the proposed automated system will be subjected to the simulation experiment by applying it on two construction sites based in Egypt, then comparing the results of its generated solutions to the original solutions executed in the construction sites to examine the proposed automated system accuracy and effectiveness. The simulation experiments conducted in this research are further explained in chapter 6 together with the findings.

For the evaluation process, this research will be designed to use testing and experimental strategies. Testing strategy in terms of functional (black-box) and structural (white-box) tests will be used to check the proposed automated system functionality and errors in its interfaces or in execution of any commands during the testing. The results of the previous tests will be used to evaluate the proposed automated system completeness and performance. Experimental strategy in terms of controlled experiment will be used to examine the proposed automated system usability, functionality and user acceptability. Control experiment has been chosen as an evaluation strategy for this research as it has the high internal validity and control

(Whitley, 1996). The controlled experiment conducted in this research is further explained in section 4.7.

#### **4.6. DATA COLLECTION AND ANALYSIS METHODS**

There are many data collection methods for the grounded theory, survey, testing and experimental strategies which are utilized in the different stages of this research methodological approach. The methods of the data collection contain and not restricted to literature review, interviews, questionnaires, observations, group discussions and past records (Abuelma'atti, 2012; Johannesson & Perjons, 2012). However, this research is designed to use grounded theory and survey strategies for the first stage of its methodological approach which is the pre-development stage as mentioned before in section 4.5. The grounded theory strategy data collection is done through literature review method. Literature review in chapter 2 is carried out to explicate the research problem in order to more clearly formulate a precise problem. Generally, literature review is a step that is carried out initially of a research in order to achieve at least one of the following purposes (Hart, 1998):

- Differentiate what has been done from what needs to be done.
- Explore important variables relevant to the topic.
- Analyze and gain a new perspective.
- Distinguish relationship between ideas and practice.
- Substantiate the context of the topic or problem.
- Improve and acquire the subject vocabulary.
- Comprehend the structure of the subject.

- Attach ideas and theory to applications.
- Identify the main methodologies and research techniques available.
- Emplacement the research in a historical context to show familiarity with state-of-the-art developments.

Literature review is a way of knowing what is already known in the research area. In addition, it is also a method of involving in scholarly review based on the researcher reading and understanding of the work of others in the same field. Furthermore, it considers as a process of interpreting what have been achieved and using their ideas as evidences to support or clarify a particular viewpoint or argument (Bryman, 2008). However, the purposes of exploring the existing literature review in chapter 2 are introduced below:

- To develop an understanding of site layout planning within the construction industry.
- To identify the site layout planning current practices and challenges.
- To identify the existing concepts and theories those are relevant to the site layout planning area.
- To explore existing automated systems to define their limitations, shortcomings, controversies and their successful utilizations.
- To identify the existing concepts and theories those are relevant to the site layout planning area.
- To identify research approaches, methods and strategies of the research that have been identified to study the site layout planning area.

Whereas the survey strategy data collection is done using questionnaires method. The considerations for the targeted survey sample location and participants are summarized in the following table.

Table (4. 5): Considerations for the targeted survey sample location and participants.

<b>Sample location</b>	The survey data collection exercises were held in the Egyptian construction sites as Egypt is the case study for this research to capture the real sites layout circumstances and the proposed automated system end users' requirements.
<b>Sampling for survey</b>	<p>The sample used in this survey is targeting different positions of the construction industry practitioners with experience more than fifteen years of working on Egyptian sites as Egypt is the case study for this research. The purpose behind seeking this huge experience is for reducing the research sample. This is because when taking someone who is a pioneer in this field, the benefit and feedback will be more than from someone with less experience.</p> <p>Furthermore, the sample also targets both the private and public construction sectors in Egypt in order to have a comprehensive feedback about the real sites layout circumstances and the end users' requirements that representing both sectors. Moreover, this sample targets the companies with work budgets more than twenty million Egyptian pounds. This is because the mentioned companies are those who consider the planning tasks for better utilizing for spending their money.</p> <p>The construction industry practitioners – targeted by this sample – should have either developed or participated in a project with site layout plan. In other words, those practitioners should be specialized in order to be able to judge better on the questions included and give reliable feedback</p>

	based on their work in real sites. Therefore, the accuracy and reality of the results will be guaranteed.
<b>Response rate 75%</b>	Based on the above criteria of the survey sample, sixteen construction industry practitioners from public and private sectors (8 from each sector) were picked and received the questionnaires. Twelve questionnaires were returned (4 from private sector and 8 from public sector) which achieve of 75% response rate. The response rate of 75% is acceptable and it is in line with the opinions of Akintoye (2000); Dulaimi, Ling, and Bajracharya (2003); Takim, Akintoye, and Kelly (2004). As they reported that the normal response rate in the construction industry for questionnaires is around 20-30 %.

Questionnaires (Appendix A) as discussed before in chapter 3, are utilized to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real construction sites. The Collection of data for surveys through questionnaires has both strengths and weaknesses. The questionnaire is anonymous, yet it helps to avoid interviewer bias. Moreover, it gives the chance to examine a broad range of issues such as those envisaged in this research, although it has some limitations like a low response rates. However, the researcher has no control on the conditions under which the questionnaire is accomplished (Neuman, 2005).

The questionnaire developed based on close ended questions to make it as easy to complete as possible to enhancing the response rate, as suggested by Dlakwa (1990). The layout and format of the questionnaire are also given consideration to ensure that respondents do not inadvertently miss questions. Therefore, a sample of the ten-page

questionnaire could be seen in appendix (A). The questionnaires purpose and data analysis stage were discussed before in chapter 3 together with the findings.

According to the third stage of this research methodological approach which is the post-development stage; it includes two processes: validation and evaluation of the proposed automated system. This research is designed to use experimental strategy in terms of simulation for the validation process to examine the proposed automated system accuracy and effectiveness as mentioned before in section 4.5. The simulation experiment data collection is done using observations method. Marshall and Rossman (1989) define observations as "the systematic description of events, behaviors, and artifacts in the social setting chosen for study". Furthermore, observations can be used to help answer descriptive research questions, to build theory, or to generate or test hypotheses (DeWalt & DeWalt, 2002). In this research, observations will be used to check, verify and compare the results of the proposed automated system to a real-world environment (real construction sites) to examine its accuracy and effectiveness for the validation process. Therefore, the analysis of observed results will complete based on the results comparison. The results comparison discussions are further explained in chapter 6.

Whereas for the evaluation process, this research is design to use testing and experimental strategies. Testing strategy will be in terms of Functional (black-box) and structural (white-box) tests as mentioned before in section 4.5. Testing data collection is done using observations method. DeWalt and DeWalt (2002) suggests that observation could be used as a way to conduct the evaluation process of a research, as observations may help the researcher to have a better understanding of the context and phenomenon under research. The same authors further argue that observations are a process that enables the researchers to learn about the performance of the artifact

under study in the natural setting through observing its performance in executing different orders through a test experiment. This suited with the purpose of using observations in this research as it will use to check, verify and evaluate the performance and completeness of the proposed automated system through the previously mentioned tests as will discuss in sections 4.7 and 6.7.

While experimental strategy will be in terms of controlled experiment as mentioned before in section 4.5 The controlled experiment will execute through a typical experimental method which is the user trial method to examine the proposed automated system usability, functionality and user acceptability (McClelland, 1995). In order to formulate a user trial, a sample of users has to be chosen to reflect the product user population as whole. According to McClelland (1995), this means that selecting a group of users who just do not have the same characteristics as user population, but who reflects the extent to which these characteristics vary. However, it is important that characteristics of the users to be pioneers in construction industry with more than 10 years' experience. There are two aspects in choosing the sample population. The first one is to develop the profile of the users in the population and the second one is to get the appropriate sample numbers. For the purpose of user trial of the ASLS, the main profiles of the users are professors (consultants), project managers and site engineers.

The decision on appropriate number of users for the user trial is always a difficult issue considering the literature provides a wide range of numbers with various statistical techniques. Virzi (1992) concludes that 80% of the usability problems can be detected by 4 to 5 subjects, more subjects tend to detect less and less insights as numbers increase. However, five users have been participated in this trial due to three different sets of user profiles as identified earlier in this section. Table (4.6) shows the



breakdown of the users who work in Egyptian construction sites for more than ten years.

Table (4. 6): Population sample of the User Trials

<b>Profile of the Users</b>	<b>Background Information</b>
Professor (consultant)	Construction management professor and consultant and analyser.
Professor (consultant)	Construction management and Methods professor and IT in construction consultant.
Project Manager	Project manager in the public sector who is specialist in smart design solutions at all stages in the life of a project.
Project Manager	Project manager in the private sector who is experienced in engineering design that include civil, structural, geo-technical, and geo-environmental engineering, complementary services such as development planning, traffic and highways engineering and project management.
Site Engineers	Site engineer who is specialist in urban design.

The user trial procedures and principal components are further explained in sections 4.7 and 6.7. However, the users trial data collection methods are:

- Questionnaires to collect data on the proposed automated system usability.
- Interviews to collect data on the proposed automated system functionality and user acceptability. The following sections examine these methods in detail.

#### **i. Questionnaires**

The questionnaire is used for the user's trial data collection to examine the usability of the the proposed automated system. System Usability Scale (SUS) questionnaire by

Brooke (1996) is used as a data collection method for the evaluation process as it is relatively short and more effective than other longer counterparts such as Questionnaire for User Interface Satisfaction (QUIS) and Computer System Usability Questionnaire (CSUQ) (Tullis & Stetson, 2004).

The System Usability Scale (SUS) is a ten-item attitude scale that gives a wide globally view of subjective assessments of usability (SUS-Wikipedia, 2014). According to ISO standard ISO 9241 Part 11, the context of the use of the system should be put into consideration in order to measure the usability of a system (ISO, 1998) i.e., the user of the system, the purpose of usage, and the surrounding environment in which they are using it which are further explained in sections 4.7 and 6.7, through the user trial procedures and principal components. Effectiveness, efficiency and satisfaction are different aspects of the measurements of usability. The first one has to do with the ability of users to achieve successfully their objectives. The second one has to do with the amount of effort and resource spent in achieving those objectives. The third one is the experience satisfactory (Usability-Wikipedia, 2014). Figure (4.3) shows the template of the SUS questionnaire.

The data obtained from the questionnaires are reported and analysed using the following three methods:

- Goal Achievement.
- Total Score.
- Maximum Rating.

The questionnaires data collection and data analysis stages are further explained in chapter 6 along with the findings.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
2. I found the system unnecessarily complex	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
3. I thought the system was easy to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
5. I found the various functions in this system were well integrated	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
6. I thought there was too much inconsistency in this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
8. I found the system very cumbersome to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
9. I felt very confident using the system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5

Figure (4. 3): System Usability Scale (SUS) (Brooke, 1996).

## ii. Interviews

The interview can have three forms, namely: structured, semi-structured and unstructured. In the first one, the interviewer administers a questionnaire with a very little scope to ask any additional or supplementary questions, while the interviewer introduces the topic briefly in the unstructured interview and then records the replies with no control on the length or scope of the response (Fellows & Liu, 2003). The

semi-structured interview is in between the structured and unstructured interviews because the interviewer can have a list of topic areas where the responses are recorded or can follow predetermined standard questions with some probing for clarifications and explanations (Blumberg, Cooper, & Schindler, 2005; Fellows & Liu, 2003). Therefore, semi-structured interviews were adopted for data collection to evaluate the proposed automated system functionality and user acceptability.

Although the arrangement of the interview questions should be in such a way that each question deals with a separate facet of the topic, the facets should be chosen carefully since anything that might be relevant cannot be covered due to the time limitations (Gillham, 2000). The findings of the literature review on the existing automated site layout planning systems and the captured end users' requirements were implemented during the interview questions design process.

Trialling the list of questions before going for the actual interview is recommended by Gillham (2000). Therefore, a trailing for the interview questions was done many times before they had their final form to check whether they all cover the targeted objectives and whether they are clear enough. After many iterative trials, the final questions form is structured to examine the proposed automated system functionality and user acceptability with two sets of questions as follow.

The first set was aimed to evaluate the proposed automated system functionality and whether it meet the end users' requirements. This set is consisted of five questions as below.

1. What motivates you to use this automated system?
2. Do you perceive the benefits of this automated system?
3. Do you find this automated system ease the site layout planning workload?

4. Did you find this automated system fulfilled what the user needs in such programme?
5. Did you find the generated solution by this automated system efficient in your opinion?

The second set was aimed to evaluate the proposed automated system acceptability. This set is consisted of three questions as below.

1. Do you find this automated system ease your work load?
2. Do you think the use of this automated system will improve the efficiency of site layout planning?
3. Are you willing to use this automated system?

The interviews will follow the usability tests carried out with SUS questionnaires. The interviews considerations are further explained in sections 4.7 and 6.7 through the user trial procedures and principal components.

Capturing the essence of what lessons learned from any research may be done through interpretation (Lincoln & Guba, 1985). These lessons can be the researcher's personal interpretation, a meaning derived from a comparison of the findings with literature review findings (Creswell, 2003). Consequently, the analysis of the interview data was chosen to be completed by the interpretation of the results. The interviews data collection and data analysis stages are further explained in Chapter 6 along with the findings.

This section demonstrates the data collection methods chosen in this research. In fact, it was not possible to use methods other than literature review, interviews, questionnaires and observations for this research. There were not any past records kept on the areas investigated by the research, neither group discussions were carried out

since it would not be possible to collect group of expertise in communication session to get good quality data for such practical field area during this research. The next section will explain the methodological approach followed to achieve the aim of this research.

#### **4.7. METHODOLOGICAL APPROACH**

The process steps in the Design Science Cycle have outputs at each step of it as shown before in Figure (4.2). In the first step of the process, a proposal will be an output of the problem awareness. As for the research reported in the thesis, the output, research proposal addresses the problem of construction site layout planning as discussed in section 1.2. Suggestion is to develop an automated system that is capable to cover the limitations, drawbacks and shortcomings of existing automated systems as well as providing the end users' requirements. The automated system tool, technique, structure and characteristics are produced as an output of the suggested solution. The automated system tools and techniques were discussed in chapter 3. While the automated system structure and characteristics are introduced in chapter 5. However, this research formulates the design science research process cycle into three stages to utilize them as its methodological approach. Figure (4.4) presents the methodological approach as three stages; pre-development, development and post-development.

The first two steps of the design science life cycle such as problem awareness and suggestion can be considered as a pre-development stage while last two steps of the process such as validation and evaluation as well as conclusion can be considered as a post-development stage. The development stage can be divided into system analysis and design then system development. The following sections describe these stages in details.

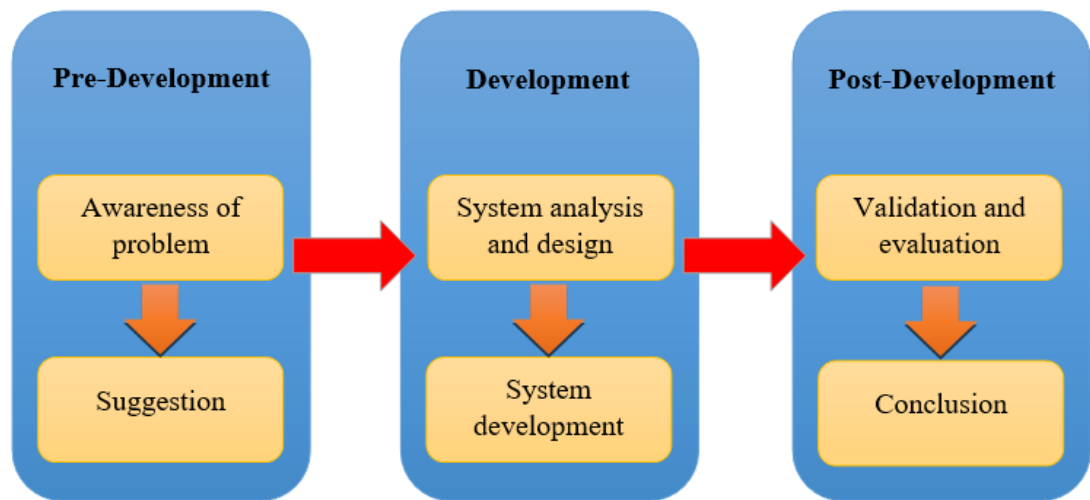


Figure (4. 4): Methodological Approach.

#### 4.7.1. Pre-Development Stage

Awareness of the problem, its identification and definition are the first steps of the design science cycle. The problem identified in the current research is to developing an automated system that offers a reasonable solution for site layout planning problems by covering the limitations and shortcomings of the existing systems and offering the end users' requirements. The purpose of a literature review conducted in Chapter 2 is to facilitate comprehension of existing theories and work by others; to produce a coherent argument for further research and to create a concrete understanding of site layout planning problems. Furthermore, it is important to gain an understanding of the current state of the site layout planning in real construction sites, in terms of its importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations to more clearly formulate an explicit and precise research problem.

Therefore, a survey for data collection from real construction sites is done in this stage using questionnaires (Appendix A) as discussed before in section 4.6. This questionnaire conducted in the Egyptian construction sites as Egypt is the case study

for this research to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning as discussed before in chapter 3.

Having identified and explicated the problem which is the first step of this stage, the research is necessary to derive suggestions which is the second step of this stage to address the research problem. Table (4.7) summaries the problem identified in the research and the proposed solutions as suggested.

Based on the comprehensive literature review conducted in chapter 2 and The collected and analyzed data form the returned questionnaires in chapter 3, the tools and techniques for the proposed automated site layout planning system have been chosen and introduced in chapter 3. The tools and techniques have been chosen as they are the suitable tools and techniques to overcome the site layout planning limitations and shortcomings as well as offer the end users' requirements. Furthermore, they are utilized to set up and formulate the structure and characteristics of the proposed automated system which introduced in chapter 5. The next section will describe the second stage of the methodological approach which is the development stage in detail.



Table (4. 7): problems and suggested solutions.

<b>Identified problem</b>	<b>Proposed suggestion</b>
Limitations of existing automated systems as discussed in section 2.5.	Develop an automated system to cover the limitations and shortcomings of existing systems as discussed in section 3.4.1.
No automated system adopted by the construction industry until now as discussed in section 2.4.	Develop an automated system based on real sites circumstances and satisfy construction site's needs.
Ignoring user interaction as discussed in section 2.5.	Develop a user friendly automated system that enable the user to input, edit and update construction layouts as discussed in section 3.4.1.
Using weak optimization techniques as discussed in sections 2.5 and 3.4.2.	Utilize a strong optimization technique suitable to the research problem as discussed in section 3.4.2.
Generated solutions are not reusable as discussed in section 2.5.	Develop an automated system with library supporting storing and retrieving previous generated solutions as discussed in section 5.2.
No efficient method to reflect the dynamic nature of construction sites.	Create a new efficient method to reflect the dynamic nature of construction sites as discussed in section 5.3.4.
Lake of attention to the surrounding environment as discussed in section 2.3.5.	Create a new objective functions to help in protecting the surrounding environment as discussed in section 5.3.5.

#### **4.7.2. Development Stage**

The literature reviews of construction site layout planning problems provides suggestions to address the research problem of developing an automated dynamic site

layout planning system to cover the limitations of the existing systems, real construction site circumstances and user's demands to help in improving the construction industry. After gaining knowledge in the first two steps, the next step is to fulfill the suggestion as discussed in the Suggestion phase.

The formulation of the targeted design is the creative effort to transform existing knowledge and a well-defined problem definition and requirements into an artifact to create a solution to the problem. This is created in this development phase where the actual design is carried out. Therefore, the resulted design science research artifact may be rather abstract in nature, such as in the form of constructs, models, or methods (March & Smith, 1995). However, this research has developed an automated site layout planning system that are required to help in improving the construction industry as discussed before in chapter 2 and 3. The development stage includes the following two steps.

- System Analysis and Design
- System Development

In the development step, an automated dynamic site layout planning system for construction sites is developed. This development stage is discussed further in chapters 5.

#### **4.7.3. Post-Development Stage**

In this post-development phase, the validation and evaluation processes of the proposed automated system are carried out as it will discuss in chapter 6. The logical consistency and coherence between validation and artifact evaluation are indispensable as the main goal of design science research is the dual effort of creating a problem-solving artifact and making a contribution to the knowledge base.

Typically, the design science research summative validity is achieved through artifact evaluation (Manuel, 2012). Whereas March and Smith (1995) contribution is rooted in the belief that apprehending reality is not direct (we can only access perceptions and representations); thus, the accuracy and effectiveness of theories can only be proven through practical applications.

Walls, Widmeyer, and El Sawy (1992) also take March and Smith (1995) path when they argue that even if a design theory has passed tests of explanatory or predictive power, they must also pass the test of practice. These understandings of validation are epistemologically placed in the same vein as pragmatism. In this view, evaluation of the resulting artifact corresponds to validation of the truthfulness of the design theory that it embodies or materializes (Venable, 2006; Walls et al., 1992). On a final note, validation should always be considered as provisional. Moreover, validation should not be thought of as a binary attribute of the theory, but rather as an evolutionary goal, aiming at perfectibility and expected to produce ever more accurate (or useful) models of reality (Manuel, 2012).

Accordingly, this research followed Venable, (2006); March and Smith (1995); Walls et al., (1992) path in executing a separate practical test for the proposed automated system validation process. In other words, the validation process treated as a separate process with its own objectives rather than being treated as one of the objectives of the evaluation process. However, this research has been ensuring the presence of the logical consistency and coherence between the validation and evaluation processes when choosing the different methods to conduct them. The choice of multiple methods enables better compromises in evaluation and validation if complementary methods are chosen (Pirainen, 2016). Choosing different methods that enable answering questions regarding not only functionality of the artifacts in its given setting, but also

examining aspects of its interplay with the users and other phenomena in the borders of the real is called complementarity (Cunliffe, 2010; Morgan & Smircich, 1980).

Therefore, the validation process conducted through experimentation in terms of simulation to examine the proposed automated system accuracy and effectiveness as mentioned before in section 4.5. The simulation experiment in this research executed based on two real construction projects in Egypt as two practical cases to compare the results of the proposed automated system with the current situation in the real-world. The result of the comparison used to validate the proposed automated system accuracy and effectiveness. The validation process through the simulation experimentation are further discussed in chapter 6.

On the other hand, there are multiple evaluation strategies, including action research, controlled experiments, simulation, or scenarios (Vaishnavi, 2004). The goodness and efficacy of an artifact can be rigorously demonstrated via well-selected evaluation strategies (Basili, 1996; Kleindorfer, O'Neill, & Ganeshan, 1998; Zelkowitz & Wallace, 1998). The choice of design evaluation strategy can vary depend on the designed artifact and the selected evaluation metrics. This research utilized testing and experimental strategies for the evaluation process as mentioned before in section 4.5. The evaluation process examined the proposed automated system completeness, performance, usability, functionality and user acceptability. Checking the system completeness and performance in execution of any commands is done through structural (white-box) and functional (black-box) tests.

The white box testing is a method of a detailed investigation of internal logic and structure of the code. In white box testing, it is necessary for the tester to have full knowledge of source code, while the black box testing is a method of testing without

having any knowledge of the internal working of the application. It only examines the functional aspects of the system (Chinmay, 2015). Table (4.6) summaries the advantages and disadvantages of both tests (Chinmay, 2015; Mohd, 2010).

Table (4. 8): The advantages and disadvantages of the structural (white-box) and functional (black-box) tests (Chinmay, 2015; Mohd, 2010).

Test	Advantages	Disadvantages
<b>The structural (white-box).</b>	<ul style="list-style-type: none"> <li>▪ It reveals error in hidden code and enable to remove them.</li> <li>▪ Side effects are beneficial.</li> <li>▪ Maximum coverage is attained during test scenario writing.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Many paths will remain untested as it is very difficult to look into every nook and corner to find out hidden errors.</li> <li>▪ Some of the codes omitted in the code could be missed out.</li> </ul>
<b>The functional (black-box).</b>	<ul style="list-style-type: none"> <li>▪ Efficient for large code segment.</li> <li>▪ Tester perception is very simple.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Only a selected number of test scenarios are actually performed.</li> <li>▪ Without clear specification test cases are difficult to design.</li> </ul>

Based on the previous advantages and disadvantages of both tests as well as to formulate efficient tests that cover all concerns and aspects, the testing process executed in two phases. Phase one will be a structural (white-box) test only based on a small artificial case to discover any errors in logic or structure of the proposed automated system code then fix them. A code debugging executed by the MATLAB debugging tool to check if any errors occur during the test as discussed before in section 3.4.1. Debugging enables to find and fix logical errors and check whether the tests run correctly. Debugging refers to halting the test execution on a certain keyword test operation or a script line and then running through the test in step with the execution, stopping on operations or script lines (The MathWorks Inc., 2013). While phase two is the functional (black-box) test to examine the functional aspects of the proposed automated system. Furthermore, the performance and results of the proposed

automated system in the functional test will help in discovering if there are any more errors in its code need to be fixed.

The white box testing applied to the unit and integration levels of the proposed automated system. White-box testing is done during unit level to ensure that the code is working as intended and to catch its defects, while it done during an integration level to test the interactions of each interface with each other (Chinmay, 2015). The black box testing treated the proposed automated system as a “Black Box” to examine its functional aspects. The testing process is further explained in chapter 6 with its finding.

According to (Preece, Sharp, Holland, & Carey, 1994), the most important concern of the evaluation process is to gather data about the usability of a design or a product by a specific group of users for a particular activity within a specified environment or work context. Therefore, examining the proposed automated system usability, functionality and user acceptability is done through a controlled experiment in terms of the user trial method as mentioned before in section 4.5.

User trial is a typical experimental method (McClelland, 1995). A user trial - the most common type of usability study – is an experimental investigation in which a group of users interact with a version or versions of the product under controlled conditions (Pheasant, 1996). User trial is regarded as synonymous to usability testing insofar as this term refers to the evaluation of an artefact under controlled conditions involving users (McClelland, 1995).

Testing the systems for the fitness to their purpose (effective, efficient and satisfying) in the process of use (user, tasks) are done through usability tests as it will be explained chapter 6. The users’ sample were selected in order to perform this usability test by

carrying out a set of tasks based on the scenarios under the watching of an evaluator (Rubin, 1994) as it discussed before in section 4.6. The evaluator plays an important role: briefing the user, annotating time, number of errors and percentage of completing for each task. The users have to subject to a psychometric questionnaire at the end of the test for checking the perceived usability and satisfaction with the performance data.

Formulating a user trial is basically about forming an environment that allows the interaction between a product and a user to be examined and measured in an organized way (McClelland, 1995). The principal components of the user trial are shown in Figure (4.5).

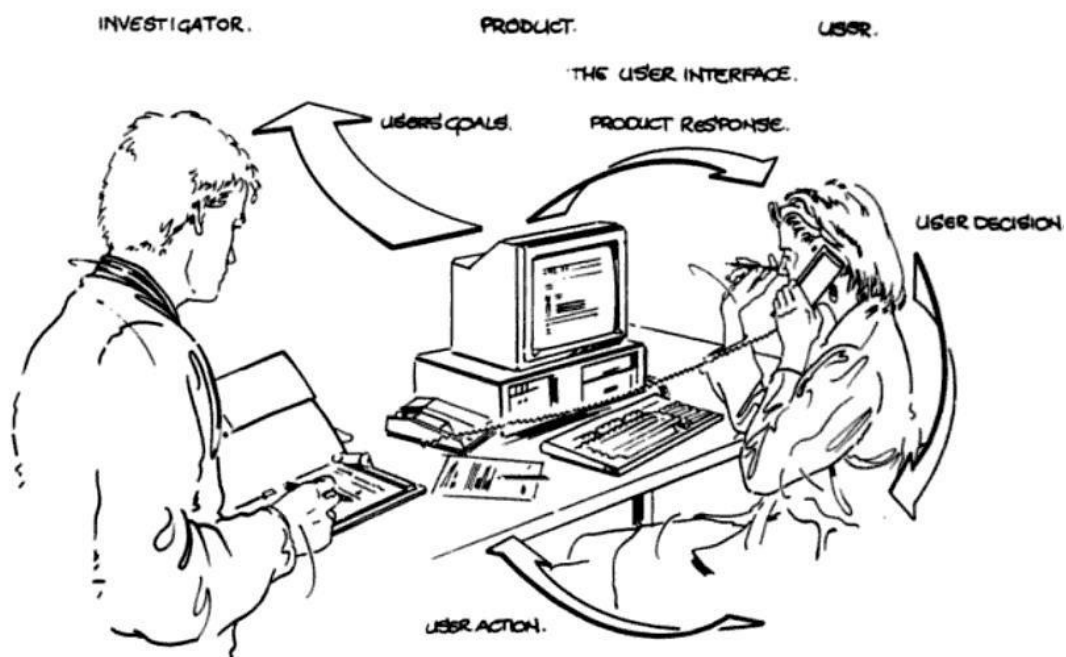


Figure (4. 5): The principal components of the user trial (McClelland, 1995).

The components of the user trials are:

- A group of users – members of the intended user population.
- The product – product or system to be used in the trial.

- A set of tasks – what users must do to achieve their goals.
- Performance criteria – the criteria that are used to judge the effectiveness of the system.
- Measurement techniques – the techniques that are used to measure the effectiveness of the user interface in enabling the user to complete their tasks successfully in terms of criteria selected.
- The site for the user trial – the location where the system is to be evaluated.
- Investigator or evaluator – the person who is responsible for the design and conduct of the user trial.

According to McClelland (1995), user trials are usually organized in the following ways:

- An introduction to the trial; purpose of the trial; the system to be used including a demonstration; tasks to be undertaken; measurements to be carried out.
- A walkthrough of the essential aspects of the trial with the user; clarify whether or not the user has understood what is required of him/her.
- Data collection; the user carries out the sequence of the tasks; evaluator takes the measurements.
- Debriefing the user; useful to get the user's view of the system; get some feedback on how well they did and how the results are likely to influence the system that they have just used.



Figure (4.6) shows the main phases in the typical user trials. Data are usually collected during or completion of each task. Pilot run is generally used as practice phase for the user.

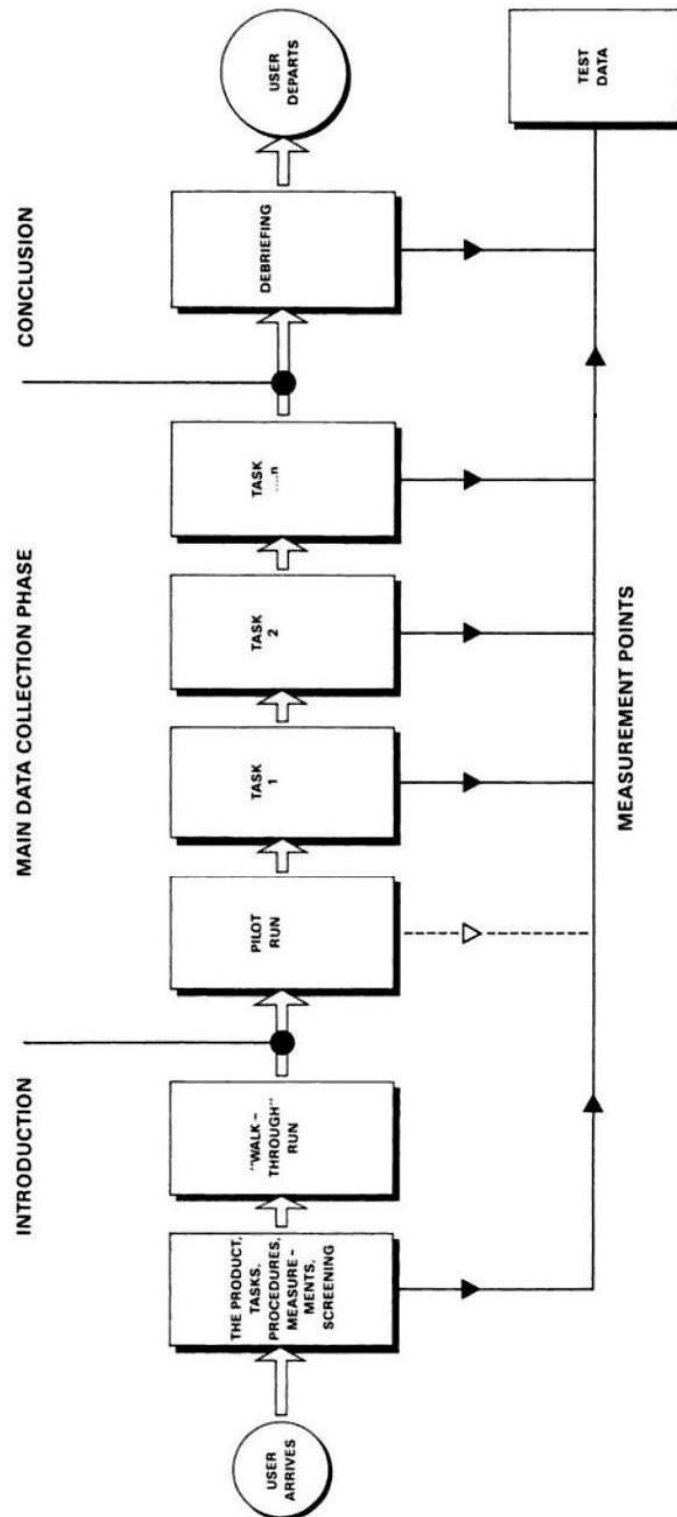


Figure (4. 6): The main phases of user trial (McClelland, 1995).

The methods used to collect data from user trials fall into the following categories:

- Questionnaire to collect data on attitude or pre-defined criteria
- Interviews to collect data on subjective assessment

The most relevant method for data collection has to be judged on the basis of the evaluation, however in practice blend of all the methods are often used. However, questionnaire and interview utilized as the data collection methods as mentioned before in section 4.6 for the user trial that will be further discussed in chapter 6.

## **4.8. SUMMARY AND CONCLUSIONS**

Research methodology is approach used in the research process starting from the theoretical groundwork to the collection and analysis of the data. On these terms, this chapter has presented and justified the research methodology – design science – adopted for this research. It is adopted to develop a solution that meets the needs of the problems identified in the domain. Regarding that, it has elaborated and justified the process involved in the theoretical groundwork related to the adoption of the research philosophies, approaches and strategies as well as methods and techniques for data collection and analysis. Furthermore, it describes the methodological approach followed to formulate this research. The previously mentioned research methodology is not the only perfect design for the research in hand; however, this chapter concluded it as the most appropriate methodology from the view of the aim, objectives and type of this research. This chapter also concluded to formulate the design science research process cycle into three stages that cover the complete research process. Next chapter will introduce the structure and characteristic of the proposed multi objective automated site layout planning system. While chapter 6 will validate and evaluate the proposed automated system.

## **CHAPTER 5**

### **STRUCTURE AND CHARACTERISTICS OF THE PROPOSED MULTI OBJECTIVE AUTOMATED SITE LAYOUT PLANNING SYSTEM**

#### **5.1. INTRODUCTION**

The structure and characteristics of any computer aided problem solving system are considered a prerequisite to develop it, because they present the information structure of parameters in terms of form, behavior and relation. As, chapter 2 identified the structure and characteristics of existing automated system in detail, this aim of this chapter is to identify the structure and characteristics used to develop the proposed multi objective automated site layout planning system. Therefore, the chapter first presents the structure of the proposed automated system and clarifies all the needed information to work. Then, the chapter explains the characteristics of the proposed automated system in terms of site representation, facilities representation, project stages, dynamic search, optimization objectives function, facilities relation matrices, distance calculation and layout constraints. Finally, the chapter discusses the expected impacts of the proposed automated system to enhance the construction sites.

#### **5.2. STRUCTURE OF THE PROPOSED AUTOMATED SYSTEM**

The proposed automated system is designed to support construction managers, planners and engineers in indicating optimal locations for all facilities on construction sites such as material and equipment storage areas, dumping areas, site offices, fabrication shops, and batch plants (Elgendi, Ahmed, Zeeshan, & Shawki, 2014). Furthermore, to cover the existing automated systems limitations and shortcomings and offer the end users' requirements as discussed in chapter 3. Therefore, the proposed automated system will implement and integrate into four main components

developed by MATLAB system as structured in figure (5.1) in order to provide the features, functions, capabilities and end users' requirements mentioned above:

1. A comprehensive multi-objective optimization engine based on genetic algorithms toolbox that integrates and optimizes the overall impact of site layout planning on construction cost, time, safety and environmental concern.
2. A database library to support storing and retrieving construction site layout data and the generated optimal solutions.
3. An Input module that facilitates the input of a project data.
4. An Output module that visualizes and retrieves the generated optimal site layout solutions (Elgendi et al., 2014).

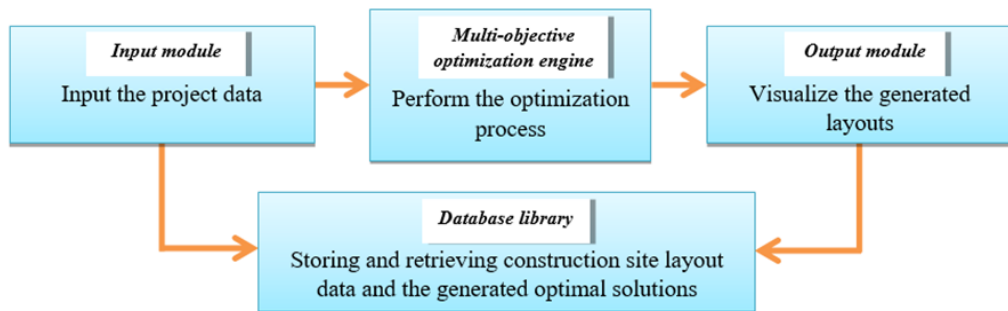


Figure (5. 1): Main components for the structure of the proposed automated system (Elgendi et al., 2014).

These components represent the basic pillars for the structure of the proposed automated system developed in this chapter. Based on the main data required to implement the site layout planning which identified in chapter 2 and 3, the proposed automated system will utilize these data as described and grouped into five major categories in Table (3.1).

Table (5. 1): Data required by the proposed automated system.

<b>Data</b>	<b>Description</b>
Project data	Main project information (name, company, location, start date, duration....). Main project stages and their duration grouped based on facility requirements or user preference.
Geometrical data	Site boundary (regular or irregular shape), fixed facilities, obstacles and protection zone name, locations, start date, duration, size, orientation, shape....
Facilities data	Dynamic and static facility name, locations, start date, duration, size, orientation, shape, relocation cost....
Facilities interactions relationship	Closeness weight relationship between facilities that represent the required objective function
Required objective function	The required objective (cost/time, safety, environmental or multiple objectives with the weight percentage of each).

These data will be used as the system input for the proposed automated system to facilitate its use and implement the site layout planning. Based on the identified structure of the proposed automated system, the next section will demonstrate the characteristics used to develop the proposed multi objective automated site layout planning system.

### **5.3. CHARACTERISTICS OF THE PROPOSED AUTOMATED SYSTEM**

#### **5.3.1. Site Representation**

According to previous studies, a common practice implemented to represent the available site space as a set of discrete cells using an orthogonal grid, and allowing facilities to be positioned only in the grid cells, without considering whether their sizes fit with the grid cells or not (which is known as equal area problems approach) (Elgendi & Ahmed, 2015). Although the space search procedure can be simplified by

using grids which reducing the number of available choices for the position of facilities, it restricts the shape of the site to the orthogonal gridlines only which is may considered as a fake representation for sites shape (Andayesh & Sadeghpour, 2013). The construction site can be at any shape in real life as well as facilities can be positioned freely in any available space on the site considering to their real sizes (which is known as unequal area problems approach) (Ning & Lam, 2013). The proposed automated system developed in this research represents and analyses the site space as a continuous space and allows the facilities to be located anywhere in the construction site (unequal area problems approach). This makes the proposed automated system closer to the reality of construction projects. In addition, the proposed automated system is not limited for certain site shapes, but it has the capability to represent and analyze any regular or irregular site shapes defined by the user in the search process as. The real representation of the construction site shape is fundamental requirements for any automated site layout planning system, as it enables the development of more realistic and efficient layouts.

### **5.3.2. Facilities Representation**

The proposed automated system is capable of analyzing any regular or irregular facilities shapes in the search process, for the first time, the user could define any irregular shape for the required facilities. This makes the proposed automated system flexible to use and close to a real site where facilities can take any shape. Furthermore, this research divides the site facilities into five groups based on the way they are involved in the search process as shown in table (5.2) (Elgendi & Ahmed, 2015). Considering that the site facilities of all types could exist on the site for a certain duration or for the entire duration of the project. Thus, the duration of which facilities

exist on the site is linked to it in the search process to enable the system of positioning the facilities only for the actual duration they exist on the site.

Table (5. 2): The site facilities groups.

Category	Description
Fixed facilities	The facilities have a known and fixed location on site and do not require to be positioned in the search process (such as the constructed or existing buildings and any other facilities need to be fixed in one position due to the user opinion) (Elgendi & Ahmed, 2015).
Static facilities	The facilities' location will be determined in the search process just one time, then their location remains fixed and do not relocate (such as tower cranes and batch plants). These facilities are not allowed to be relocated on site through any point of time due to the significant time, cost, and/or effort required to relocate them (Elgendi & Ahmed, 2015).
Dynamic facilities	The facilities' location will be determined in the search process and can be relocated at the beginning of the project stages (such as site offices, testing laboratories, storage areas and fabrication areas). A dynamic facility can be relocated at the beginning of each stage in case there is free space available through its duration that is better than its occupied location or to provide space for other facilities. However, this repositioning must be accounted for additional relocation cost (Elgendi & Ahmed, 2015).
Obstacles	The facilities have a known and fixed location on site and do not require to be positioned in the search process as well as do not have any relationship with any other facilities (such as existing buildings and trees) (Elgendi & Ahmed, 2015).

Protection zones	The zones' that location and size are defined by the user for the reason of protecting the surrounding neighbor, environmentally (such as schools, hospitals, farms or any other environmentally sensitive areas) from the harmful effect of construction activities.
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Moreover, in order to improve the practicality of the proposed automated system, it is capable of orienting the fixed facilities, obstacles and protection zones with any given angles defined by the user even those diagonal angles which are required for a special space (Figure 5.2).

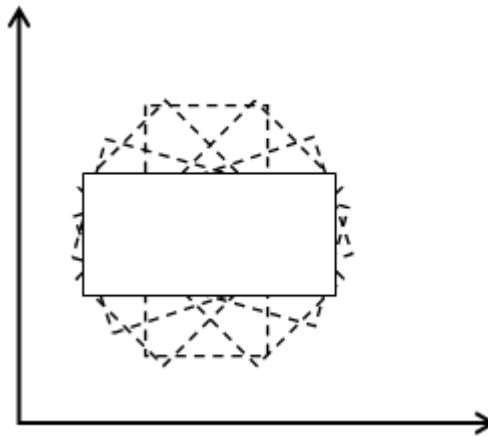


Figure (5. 2): Fixed facilities, obstacles and protection zones orientation options.

Furthermore, the static and dynamic facilities will allow to orient with angles  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $270^\circ$  only, if the user chooses to align them with angles options in the search process. Otherwise they will orient as its input shape (Figure 5.3). The reason behind this angles restriction is to minimize the GA optimization search process time.



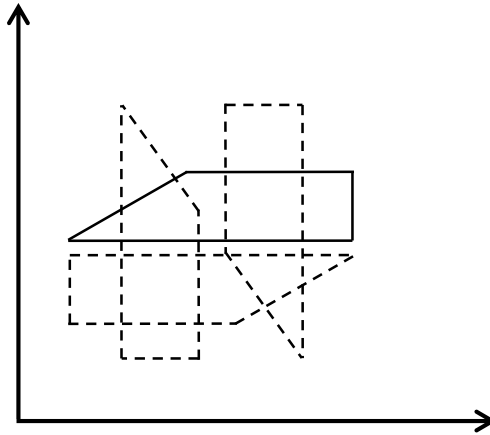


Figure (5. 3): Static and dynamic facilities orientation options.

The previous orientation options make the proposed automated system suitable and efficient for sites with irregular boundary or special space requirements and capable to generate more efficient layouts.

### 5.3.3. Project Stages

The project stages are defined as the number of time intervals that divide the project duration according to the resource and facilities needed for each time interval. Traditionally, the project duration could be divided into three successive main stages: substructure, superstructure and finishing (Nguyen, 2013). Some of the previous developed automated system oblige the user to work with these three main stages. But no methodology exists until now to define the optimum number of time intervals, order, or durations, in order to have the best result and the minimum objective function (Andayesh & Sadeghpour, 2014). Furthermore, enhancing the quality of site layout planning can be achieved by raising the number of project stages because it provides more frequent updates of the site layout needs (Said, 2010).

Therefore, in this research the user will not be limited to a specified number of project stages, but it will leave him/her the freedom to choose the appropriate number of

project stages. This is due to the variation of construction projects, more user interaction with the proposed automated system and the enhancement of the quality of the generated site layouts. Thus, the user could define any number of project stages based on the resource and facilities needed for each stage according to his/her experience, need and vision under two main condition: 1) no overlap between the stages duration; 2) the defined stages duration must cover the entire project duration.

#### **5.3.4. Dynamic Search**

The construction sites have a unique dynamic nature progresses, as the required spaces to accommodate the facilities needed to support the construction activity are subject to change during the project life (Yahya & Saka, 2014). These changes must be incorporated in the site layout to be efficient and realistic as real sites. Although a lot of automated systems have been developed, they are different in the approaches they utilize to reflect the site changes (dynamic nature) over the project duration in site layout planning. These approaches can be identified in two main types which are the Static and the Dynamic approaches. Although the dynamic approach could be implemented in various methods with different names, but they eventually have the same goal which reflects the dynamic nature of construction sites. Therefore, these implementation methods could not be considered as a main approach, but as a sub-approach that falls under the main dynamic approach. The two main approaches with their implementation methods, advantages and disadvantages will be explained in detail in the next section with introducing the new method that is utilized in this research to reflect the dynamic nature of construction sites under the main dynamic approach.

#### a) Static Approach

The static approach assumes that all site facilities exist and fixed in size and location for the entire project duration (Ning et al., 2010). This assumption does not allow the reuse of space between facilities. A lot of studies adopted the static approach in developing their automated site layout planning systems such as Easa and Hossain (2008); Khalafallah and El-Rayes (2011); Lam et al. (2009); Lien and Cheng (2012); Ning and Lam (2013); Wong et al. (2010).

These automated systems ignore the changes that occur on construction sites over the project's duration and develop one layout for the entire project duration. The facilities location search process in this automated systems are done without incorporation of the facilities duration on site; therefore, they are considered a very simple search process. The static automated systems may be suitable for short duration projects where only a few changes that may occur on the site or for large area projects where there are a lot of space available (Andayesh & Sadeghpour, 2014). But the static automated systems are limited and cannot be used practically for complex projects with long duration where numerous facilities arrive and leave the site during project's duration or for small area projects where space reuse is significant action.

#### b) Dynamic Approach

To overcome the limitation of static automated systems, the studies focus on the dynamic approach to develop dynamic automated systems (Xu & Li, 2012). The dynamic approach assumes that all changes happen in construction site for the entire project duration must be reflected in the site layout (Isaac et al., 2012). Accordingly, this approach adds the time factor to the optimization of site layouts which consider as an important challenge in site layout planning. Because the incorporation of time

factor turns the optimization problem to be more complicated by upgrading the construction site layout problem from a 2D or 3D optimization problem – that only includes physical dimensions – into a 4D optimization problem which includes the time dimension to the physical dimensions (Andayesh & Sadeghpour, 2014).

Although, developing an automated site layout planning systems based on the dynamic approach is considered a challenging and complex problem, a lot of studies adopted it for its suitability to the dynamic nature of construction sites. These studies which apply the concept of the dynamic approach in different methods will be explained in the next paragraphs.

Some of these studies apply the dynamic approach by dividing the project duration into several successive stages. Then, they identify the available site space and facilities needed to support construction activities in each stage such as AbdelRazig, El-Gafy, and Ghanem (2006); Elbeltagi et al. (2004). The stages duration in these automated systems could be fixed according to the developer judgment or could be defined according to the user experience.

Each stage is optimized separately in a chronological order starting from the first stage till the last one. A layout generated for each stage is considered completely separate from others successive stages layout. Facilities from previous stage that continue to the next stage are considered fixed in the location they have been allocated to in the previous layout, while the new facilities that enter to the site in that stage are optimized in the remaining available space. As a result, these automated systems allow the reuse of space from one stage to another.

Although these automated systems allow the reusing of spaces which have become vacant during one stage in its succeeding stage, the space reuse within each layout is

not allowed. Furthermore, each stage layout optimizes separately in a chronological order with no consideration to the future effects on the layout quality of subsequent stages as a result of layout decisions in the early construction stages. a non-optimal dynamic layout plan or; moreover, infeasible layout plans in later construction stages would be a result of ignoring the future effects especially when more important facilities (such as batch plant) arrive on the site during these later stages of the project (Said & El-Rayes, 2013). In addition, these automated systems generate optimal site layouts for each stage, combining these separately optimal layouts may not lead to a layout that is considered optimum over the entire project duration (Andayesh & Sadeghpour, 2014).

Later in (2013), a study by Said & El-Rayes offers an automated system to overcome the inefficient strategy of future effects of the previous studies. This automated system applies the dynamic approach by dividing the project duration into a number of successive stages and generates a layout for each stage in a chronological order putting into consideration of the effects of first stage layout decisions on the layouts of subsequent stages. Any decision taken to specify the location and orientation of facility used in the first stage affects the next ones in the short-term and long-term futures. The short-term future effect represents the impact of positioning a facility on the layout decisions of the other facilities in the same construction stage. The long-term future effect represents the impact of positioning a facility on the layout decisions of other facilities in the future stages. This automated system defines the facilities into three types: fixed, moveable and stationary facilities and enables the moveable facilities type (such as site offices, storage areas, and parking) to be relocated at the beginning of each construction stage with an additional relocation cost.

Although this automated system makes consideration in locating facilities with the short-term and long-term futures effects. It has some disadvantages such as the future effect that is approximately calculated as computing it precisely in a reasonable time is hard. The location of facilities in later stages is under the influence of those in earlier ones. Thus, if important facilities (e.g. batch plant and tower crane) arrive to the site in later stages of the project, this approach will be ineffective in that case. It also allows the facilities to relocate between stages only, but within each stage layout relocation is not allowed. Furthermore, it utilizes 2D representation for the site boundary and facilities and unreal travel path between facilities. These disadvantages might lead to inefficient site layouts. In addition, it generates optimal layouts for projects stages only.

Furthermore, a recent study conducted by Andayesh and Sadeghpour (2013) presents a new automated system that applies the dynamic approach putting into consideration the actual duration of facilities on the site, and generates dynamic layouts that are optimized over the whole duration of the project while considering the dynamic changes on the site. The search process in this automated system applies the physics principle of the Minimum Total Potential Energy (MTPE) by engaging all facilities required in the search simultaneously, to compete for space only for the durations they exist on the site.

Allowing for facilities to compete for space only for the durations they exist on the site means facilities that are required later in the project can reuse vacant spaces of finished facilities. Furthermore, engaging all the facilities in the search process simultaneously provides the facilities that are required later in the project an equal chance to compete over desired locations with facilities that are required earlier on, and when they have a time overlap. Facilities with higher influence on the overall

fitness of the layout will get the desired locations regardless of their time of arrival to the site.

Although this automated system presents a new method to apply the dynamic approach and allows the reusing of spaces which have become vacant, it has serious drawbacks in representing the facilities required in the construction site by their minimum bounding circles to facilitate the search and optimization process (Figure 5.4). This representation will decrease the quality of the solution because the facilities will not represent with its true sizes but with bigger sizes. So, the site spaces will be wasted especially in projects with large number of facilities.

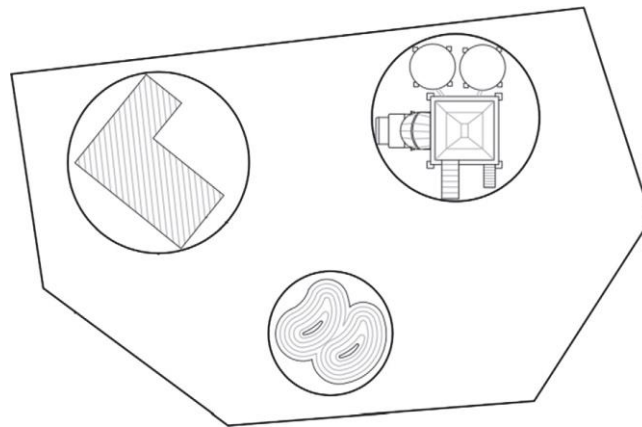


Figure (5. 4): Facilities representation with their minimum bounding circles  
(Andayesh & Sadeghpour, 2013).

Furthermore, applying the search method on the entire project duration holds some site spaces unused for later facilities with higher relation if they overlap with earlier facilities. Whereas, applying this method with dividing the project into successive stage and allowing for facilities to relocate between stages may help in decreasing the number of unused reserved spaces. By allowing for the earlier facilities to be located in the desired spaces then relocated between stages to clear spaces for the later facilities when its arrive to the site. This may lead to enhancing the developed layout

although there is a relocation cost that may be added to the layout cost. So, that method may be suitable for project with short duration and small number of facilities.

Although the previous approaches introduced methods to reflect the site changes (dynamic nature) over the project duration in site layout planning, they have some limitations may lead to inefficient site layouts as mentioned above. Therefore, this research will introduce a new method to apply the dynamic approach to reflect the dynamic nature of construction sites. The search process in the proposed automated system will be implemented in two steps. In the first step, the search process will be implemented by adopting the search method introduced by Andayesh and Sadeghpour (2013) in involving all facilities (Except the fixed facilities, obstacles and protection zones which already have a known and fixed location) required in the search simultaneously, to compete for the available space only for the durations they exist on the site with the allowing of the reuse of spaces which have become vacant. If two facilities have a time overlap and dispute over the same location, facilities with higher influence on the overall weight of the layout will get the contested locations regardless of their time of arrival to the site. In this step, a dynamic site layout will be generated for the entire project duration with the consideration of the actual duration of facilities on site and the total layout weight is calculated. If the project which is examined by the proposed automated system does not have more than one stage, then the generated layout will consider the optimal layout and the search process will end, as well as the proposed automated system will produce the solution report. If the project which is examined by the proposed automated system has more than one stage, then the search process will continue to the second step.

In the second step, the search process will be implemented by dividing the project duration into the successive stages defined by the user regardless of its number, then



the fixed and obstacle facilities located in their defined spaces along the different stages. For the first stage, the static and dynamic facilities needed in this stage will only temporarily locate same as their initial location resulting from the generated entire project layout from the first step. Then, a new search process will be implemented for the static and dynamic facilities for new optimal locations form the available space during the stage duration. This search process will be applied according to the same principle of the search process implemented in the first step.

The search process for the static facilities must be considered for the fixed and obstacle facilities location from later stages because the static facilities cannot be relocated at any point of time. If there is any overlap between the new locations for the static facilities and the fixed and obstacle facilities location from later stages, the fixed facilities will remain in its initial location and will not relocate. But if there is no overlap, the static facilities will relocate to the new optimal locations. The search process for the dynamic facilities will not be considered for the fixed and obstacle facilities location from later stages because it could relocate at the beginning of each later stage. So if a new location found for the dynamic facilities, it will automatically relocate to it. Although the relocation expression is mentioned here, there is no additional cost added in this first stage for the static and dynamic facilities because they did not actually locate. Then, an optimal layout will generate with the final locations for all the facilities for the first stage.

For the later stages, the search process will include the facilities continued from the previous stage and the new facilities that enter the site in these stages. This search process will be implement exactly as the search process in the first stage. But in these later stages, there is an additional cost that will be considered if any dynamic facility is relocated. After the search process for all stages finished, each stage will have its

own optimal site layout with its weight value. Then, the total layouts weight value will be summed up. Finally, a comparison between the layout weight value of the entire project duration layout generated in first step with the total layouts weight value for the stages layouts generated in second step will take place. The layout with the minimal weight value will be chosen and become the optimal solution for the project which examines.

The method introduced in this research provides improvements to the previous methods mentioned before, by enabling the reuse of the vacant spaces in the same stage as well as facilities relocation between stages and that through the facilities actual duration for the optimal representation to the dynamic nature of the construction sites. In addition, this method presents an innovative idea for testing the suggestion of generating optimal dynamic layouts for the project entire duration and the project stages as well, then, selecting the better between them based on the total layout weight to be the project layout.

#### **5.3.5. Optimization Objective Functions**

The objective of the research is to optimize the dynamic layout problem under multi objective optimization functions (MOO) to mimic the objective of real sites. Three congruent objective functions are employed in this research to generate optimal dynamic layouts for construction project. The first objective function ( $f_1$ ) is minimizing the total handling cost and time of interaction flows between the site facilities in order to reduce cost and time of the construction projects. The second objective function ( $f_2$ ) is minimizing the likelihood of accidents happened in order to improve the safety level. The third objective function ( $f_3$ ) is minimizing the harmful effect of construction activity on the surrounding neighboring in order to grab attention

to the environmental concern. The objective functions ( $f_1$ ), ( $f_2$ ) and ( $f_3$ ) are mathematically defined as follows:

$$f_1 = \sum_{P=1}^P \sum_{i=1}^n \sum_{j=1}^n C_{ij} RD_{ij} T_{ij} \quad \text{equation (5. 1)}$$

This objective function ( $f_1$ ) is to minimize the total handling cost and time of interaction flows between the site facilities based on the proximity weight ( $C_{ij}$ ) defined by the user that reflects the cost and time closeness relationship between any pair of facilities  $i$  and  $j$  and the real travel distance ( $RD_{ij}$ ) between them during their interaction duration ( $T_{ij}$ ) in the same stage duration over the entire project duration in order to reduce cost and time of the construction projects.

$$f_2 = \sum_{P=1}^P \sum_{i=1}^n \sum_{j=1}^n S_{ij} e_{ij} T_{ij} \quad \text{equation (5. 2)}$$

This objective function ( $f_2$ ) is to minimize the likelihood of accidents happened based on the proximity weight ( $S_{ij}$ ) defined by the user that reflects the safety concern closeness relationship between any pair of facilities  $i$  and  $j$  and the Euclidean distance ( $e_{ij}$ ) between them during their interaction duration ( $T_{ij}$ ) in the same stage duration over the entire project duration in order to improve the safety level.

$$f_3 = \sum_{P=1}^P \sum_{i=1}^n \sum_{z=1}^n V_{iz} e_{iz} T_{iz} \quad \text{equation (5. 3)}$$

This objective function ( $f_3$ ) is to minimize the harmful effect of construction activity on the surrounding neighboring based on the proximity weight ( $V_{iz}$ ) defined by the user that reflects the environmental concern closeness spatial relationship for the sensitivity of facility  $i$  is to be located in the environmental protection zone  $z$  and the Euclidean distance ( $e_{iz}$ ) between them during their interaction duration ( $T_{iz}$ ) in the

same stage duration over the entire project duration in order to grab attention to the environmental concern.

Where:

P: number of project stages (the proposed system will consider the project duration for a project with no stage number as one stage).

n: number of all type of construction facilities.

i,j: facility i and facility j.

$C_{ij}$ : a relative proximity weight that reflects the cost and time closeness relationship between facilities i and j (will explain in section 5.3.6).

$RD_{ij}$ : real distance between facilities i and j (will explain in section 5.3.7).

$T_{ij}$ : the interaction duration between facilities i and j durations during the stage duration over the entire project duration.

$S_{ij}$ : a relative proximity weight that reflects the safety concern closeness relationship between facilities i and j (will explain in section 5.3.6).

$e_{ij}$ : Euclidean distance between facilities i and j (will explain in section 5.3.7).

z: protection zone.

$V_{iz}$ : a relative proximity weight that reflects the environmental concern closeness spatial relationship for the sensitivity of facility i is to be located in the environmental protection zone z (will explain in section 5.3.6).

$e_{iz}$ : Euclidean distance between facility i and protection zone z (will explain in section 5.3.7).

$T_{iz}$ : the interaction duration between facility  $i$  and protection zone  $z$  durations during the stage duration over the entire project duration.

Since the multiple objective functions defined in this research are congruent, they can be transformed into single objective function using the following equation:

$$\text{Objective function} = \min (w_1 \cdot f_1 + w_2 \cdot f_2 + w_3 \cdot f_3) \quad \text{equation (5. 4)}$$

Where  $w_1$ ,  $w_2$  and  $w_3$  are weights defined by the user for the three congruent objective functions respectively. This method is called weighted sum method, which is a method combining a set of objectives into a single objective by pre-multiplying each objective with a user defined weight (Deb, 2001) to solve and minimize multi objectives optimization problems.

Furthermore, to calculate the layout weight for each project's stage a weight for a relocation cost (RC) will be added to each layout stage if any dynamic facility has been relocated except in the first stage there is no relocation cost added. The relocation cost (RC) can be mathematically defined as follows:

$$RC = \sum_{i=1}^m F_i + R_i^{1-k} RD_i^{1-k} \quad \text{equation (5. 5)}$$

This equation aims at calculating the dynamic facility relocation cost (RC) and comprises two cost components. First component ( $F_i$ ) which is a proximity weight defined by the user to reflect the cost of dismantling and erecting of dynamic facility  $i$ . Second component to calculate the cost of moving dynamic facility  $I$  to new location based on the proximity weight ( $R_i^{1-k}$ ) defined by the user that reflects the relocation cost for transport dynamic facility  $i$  one meter from its old location  $l$  to the new

location  $k$  and the real travel distance ( $RD_i^{l-k}$ ) from the old location  $l$  to the new location  $k$ .

Where:

$m$ : number of dynamic facilities.

$i$ : dynamic facility  $i$ .

$F_i$ : a relative proximity weight from 0 to 1000 with increment of 100 that reflects the cost of dismantling and erecting of dynamic facility  $i$ .

$R_i^{l-k}$ : a relative proximity weight from 0 to 9 that reflects the relocation cost for transport dynamic facility  $i$  one meter from its old location  $l$  to the new location  $k$ .

$RD_i^{l-k}$ : real distance between locations  $l$  and  $k$  for dynamic facility  $i$  (will explain in section 5.3.7).

$l$ : old location for dynamic facility  $i$ .

$k$ : new location for dynamic facility  $i$ .

This relocation cost will be calculated to express the cost of relocating the dynamic facilities. The relocation cost is calculated for each dynamic facility at the beginning of the stage if any of the following two conditions is occurred: (1) the orientation of a facility is changed. (2) the location of a facility is changed.

### **5.3.6. Facilities Relation Matrices**

The movement of resources between facilities, or basically the interactions among the facilities significantly influences the facilities placement on site. These interactions are called the closeness (or proximity weights) relationship between facilities and it represents the distance of the facilities close or far from each other (Hegazy &

Elbeltagi, 1999). Closeness relationships often represented aspects that are related to the cost, time, productivity or safety and environmental concerns. Although the closeness relationships could be considered as the actual amount of material exchanged between facilities or the actual transportation cost. However, relative values are often preferred to demonstrate how close or far two facilities are desired to be located due to the difficulty to determine the exact amount of materials, frequency and cost of work flows between facilities at the planning stages of the project (Elgendi & Ahmed, 2015). This research using three proximity weights in order to represent the interaction closeness relationship between facilities for the three desired objectives (explained in section 5.3.5).

$C_{ij}$ : in the first objective function ( $f_1$ ) is a relative proximity weight that reflects the cost and time closeness relationship between any pairs of facilities. Six governing factors will be utilized to set the  $C_{ij}$  closeness weight between any pairs of facilities for the handling cost and time, as follows:

1. Equipment work flow (EF): transportation and movement of equipment on site and so forth from one facility to another.
2. Material work flow (MF): transportation and movement of materials on site and so forth from one facility to another.
3. Personnel flow (PF): movement of engineer, staff and labours on site and so forth from one facility to another.
4. Information flow (IF): communication and distribution of information on site and so forth from one facility to another.

5. Time preference (TP): time factor to locate any two facilities close or far from each other.
6. User preference (UP): user desire to locate any two facilities close or far from each other.

To identify the  $C_{ij}$  closeness weight, there will be six relation matrices (Table 5.3) that express the six governing factors. The user has to fill the relations between facilities with a 9-point scale. 9 indicates a significant relationship between two facilities according to governing factor and the user would like to put the facilities as close as possible. On the other hand, 0 indicates that facilities should be assigned far away from each other according to governing factor. Then, the proposed automated system will calculate the average value for  $C_{ij}$  based on the six governing factors.

$S_{ij}$  : in the second objective function ( $f_2$ ) is a relative proximity weight that reflects the safety concern closeness relationship between any pairs of facilities. To identify the  $S_{ij}$  closeness weight, there will be a relation matrix (Table 5.3) where the user has to fill the relations between facilities with a 9-point scale. 9 indicates that the user would like to put the facilities as close as possible. On the other hand, 0 indicates that facilities should be assigned far away from each other.

Table (5. 3): Example of relation matrix to identify the  $C_{ij}$  and  $S_{ij}$  closeness weights.

Facility name	Site gates	First aid office	Time keeper office	Security office	Project staff office
Project manager office					
Project staff office					
Security office					
time keeper office					
First aid office					

■ Shaded cells fill with number on the scale 0→9



$V_{iz}$  : in the third objective function ( $f_3$ ) is a relative proximity weight that reflects the environmental concern closeness spatial relationship for the sensitivity of facility to be located in environmental protection zone  $z$ . To identify the  $V_{iz}$  closeness weight, there will be a relation matrix (Table 5.4) where the user has to fill the sensitivity weights between the facilities and protection zones with a 9-point scale. 9 indicates that the facilities could be located in the protection zone. On the other hand, 0 indicates that facilities should be located far away from the protection zone.

Table (5. 4): Example of relation matrix to identify the  $V_{iz}$  closeness weight.

Facility name	protection zone
Project manager office	
First aid office	
Batch planet	
Tower crane	

■ Shaded cells fil with number on the scale 0→9

### 5.3.7. Distance Calculation

For determining the first objective function that minimizes total handling cost and time of interaction flows between facilities, this research will consider the real distance between facilities. The real distance represents the actual travel distances between facilities without neglecting the presence of obstruction between them for more reliable results. Obstruction can be a building under construction or any other facility. In the real distance calculation, if an obstruction exists in the travel path between two facilities, the path is modified to avoid passing through the obstruction via the shortest path as shown in figure (5.5).

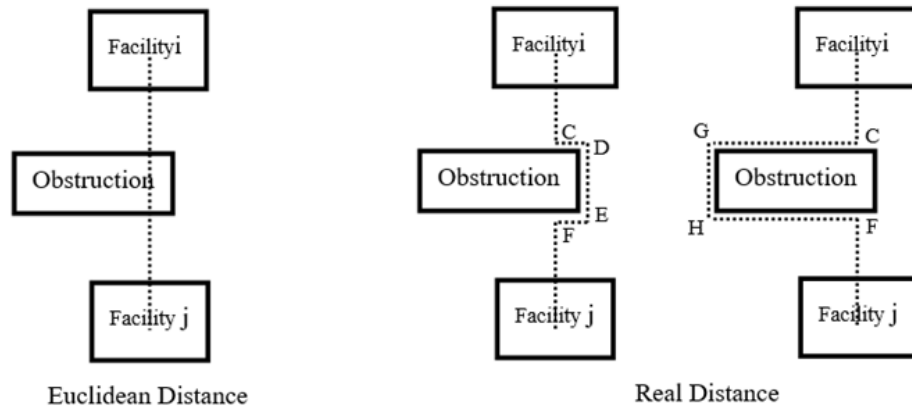


Figure (5. 5): Distance calculation approach.

For example, in figure (5.5) there are two possible paths for the real distance to avoid passing through the obstruction. The first path i, C, D, E, F, j is the shortest one. So the proposed automated system will choose it and measures the travel distance between Facility A and Facility B by calculating the length of path i, C, D, E, F, j. The real distance  $RD_{ij}$  is the result of adding the minimum obstruction distance (C, D, E, F) to the distance i, C and F, j and mathematically represented as follows:

$$RD_{ij} = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} + CDEF \quad \text{equation (5. 6)}$$

Where  $(x_i, y_i)$  and  $(x_j, y_j)$  are the coordinates of the centroids of facility i and j respectively (Figure 5.5).

For determining the second and third objectives function that maximize safety and environmental concerns the Euclidean distance is considered as the safety and environmental issues depends on closeness of facilities rather than travel distance and mathematically represented as follows:

$$\text{Euclidean distance} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad \text{equation (5. 7)}$$

### 5.3.8. Layout Constraints

The layout constraints are a set of geometric rules used to govern the process of positioning the facilities (El-Rayes & Said, 2009; Sadeghpour, 2004). However, the layout constraints in this research can be categorized in two main groups: default and optional constraints. The default constraints will be classified into two main categories and examined automatically by the proposed automated system for all facilities as detailed in table (5.5).

Table (5. 5): The layout constraints. (Easa & Hossain, 2008; El-Rayes & Said, 2009).

Constraint	Description
Boundary constraints	They are examined in the proposed automated system for each optimization process in order to ensure that the static and dynamic facilities are located within the boundaries of the site. As well as, guarantee that fixed facilities, obstacles and protection zones location input by user are correctly located within the boundaries of the site.
Overlap constraints	They are examined in the proposed automated for each optimization process in order to ensure that no overlap occurs between any pair of facilities.

While the optional constraint is imposed in the optimization process to comply with safety requirements on site, it will be expressed by a minimum distance added by the user if it is required. This is achieved to provide safety buffer distance around facilities shape area and minimize the hazards of falling objects.

Based on the identified structure and characteristics of the proposed automated system that will enable it to cover the existing automated systems limitations and shortcomings and offer the end users' requirements, the next section elaborates on the expected impacts of the proposed automated system on the construction industry.

## **5.4. THE PROPOSED AUTOMATED SYSTEM IMPACTS**

The proposed automated system is expected to have positive impacts on: (1) optimizing site layout and space planning (2) maintaining construction projects cost and time; (3) improving the overall safety of construction sites; and (4) protecting the surrounding environment.

### **5.4.1. Impact on Site Layout Planning**

This proposed automated system will be developed to suit the unique dynamic nature of construction sites, overcome the inefficiencies of existing automated system, meet the real life needs and to generate optimal plans for safer, environmental friendly and more productive construction sites. The proposed automated system utilizes global optimization approaches and tools to consider the impact of actual duration for construction facilities on the quality of layout plans. Moreover, it generates the optimal site layout from project entire duration or project stages that depend on each project objectives. Furthermore, this automated system is designed to consider all relevant characteristics of construction facilities such as space reuse and relocation feasibility, as well as various operational, safety and environmental layout constraints.

### **5.4.2. Impact on Construction Projects Cost and Time**

This automated system will hold a strong potential to maintaining construction projects cost and time by generating efficient construction site layouts that alleviate the negative impacts of exceeding project budget and duration. The efficient site layout plans maintain construction projects cost and time by minimizing the travel distances and times between storage areas to activities areas for construction crews and materials on site. Also, it eliminates the waste of time and cost that could result from the relocation of inadequate facilities allocation or poor communication.

Furthermore, the proposed automated system is designed to consider various types of safety and operational constraints that would result in a safer work environment for more productive crews. Disruptions, time and cost that are the result of accidents can be reduced through a safer construction site.

#### **5.4.3. Impact on Construction Safety**

Construction planners, managers and engineers will use the proposed automated system in order to identify optimal locations for all temporary facilities on site. This automated system will support them in (i) minimizing and eliminating the dangers of falling and striking objects from facilities and cranes; (ii) reducing and minimizing the risks that resulted from the storage, transporting hazardous materials and equipment on site; and (iii) minimizing the risks of accidents that occur due to poor communication within work teams. A safer construction site will be structured with a dramatically reduced number of accidents, injuries and fatalities.

#### **5.4.4. Impact on Surrounding Environment**

Protecting the surrounding environment during construction phase is a vital importance for the construction industry because of its duty to the environment and community. Especially with the huge amount of noise, pollution and vibration during different construction stages, none of the developed automated systems consider the protecting the surrounding environment as a target before. This proposed automated system is designed to fill this research gap by developing a multi-objective optimization engine to help construction planners to minimize construction cost/time, maximize safety and maintain environmental concern. The proposed automated system has the capabilities of locating facilities that have harmful effects (such as

batch plant, hazard materials' storage and welding workshop) at a sufficient distance from protected zones.

## **5.5. SUMMARY AND CONCLUSIONS**

This chapter has presented the structure and characteristics used to develop the proposed multi objective automated site layout planning system. However, the following conclusions were drawn from this chapter:

- The proposed automated system will implement and integrate into four main components in order to provide the targeted features, functions, capabilities and end users' requirements mentioned above:
- The proposed automated system represented and analysed the site space as a continuous space and allowed the facilities to be located anywhere in the construction site. Furthermore, it represented and analysed any regular or irregular site shapes defined by the user.
- The proposed automated system represented and analysed any regular or irregular facilities shapes defined by the user. Furthermore, the site facilities were divided to five groups based on the way they were involved in the search process. The proposed automated system was capable of orienting the fixed facilities, obstacles and protection zones with any given angles defined by the user as well as the static and dynamic facilities with angles 0 °, 90 °, 180 ° and 270 ° only.
- The proposed automated system was not limited to a specified number of project stages, but it utilized any number of project stages defined by the user according to his/her experience, need and vision.

- The existing automated systems had some limitations in their approaches introduced to reflect the site changes (dynamic nature) over the project duration that may lead to inefficient site layouts.
- This research introduced an innovative dynamic space search method that reflected the dynamic nature of construction sites based on facilities actual duration.
- The proposed automated system utilized multi objective optimization functions (MOO) in order to minimize the total handling cost and time of interaction flows between the site facilities, the likelihood of accidents happened and the harmful effect of construction activity on the surrounding neighbouring.
- The proposed automated system used three proximity weights in order to represent the interaction closeness relationship between facilities for the three desired objectives.
- The proposed automated system considered the real distance between facilities in determining the first objective function, while it considered the Euclidean distance in determining the second and third objectives.
- The boundary and overlap constraints set as the default constraints which used to govern the process of positioning the facilities, while the minimum distance that added by the user as the optional constraint which used to provide safety buffer distance around facilities shape.
- The proposed automated system was expected to have positive impacts on the construction industry in terms of: (1) improving the site layout and space planning (2) maintaining the construction projects cost and time; (3) improving the overall safety of construction sites; and (4) protecting the surrounding environment.

The following chapter will validate and evaluate the proposed multi objective automated site layout planning system.



# **CHAPTER 6**

## **AUTOMATED SYSTEM IMPLEMENTATION, VALIDATION AND EVALUATION**

### **6.1. INTRODUCTION**

Chapter 5 presented the development stage of the Automated Dynamic Site Layout Planning System (ASLS). The main aim of this chapter is to discuss the post-development stage carried out on the ASLS. Therefore, the chapter first identifies the ASLS capabilities. Then, the chapter demonstrates the ASLS implementation process through three steps: 1) ASLS access; 2) ASLS data input or edit; 3) ASLS run. The chapter also clarifies how the ASLS will facilitate the site layout planning work in the Egyptian sites for the international and local users. The results of the genetic algorithms parameters tuning process are also presented in this chapter. Furthermore, the chapter illustrates the details of the ASLS validation process. The validation process will execute through a simulation experiment on two construction projects based in Egypt as two case studies to examine the ASLS accuracy and effectiveness. Finally, the chapter discusses the evaluation process of the ASLS. The evaluation process is carried out through functional (black-box) test, structural (white-box) test and user trial to evaluate the ASLS functionality, completeness, performance, usability and user acceptance.

### **6.2. THE ASLS CAPABILITIES**

Chapter 5 discussed the ASLS structure, characteristics and the problem representation steps. Therefore, the ASLS objective is to generate a dynamic optimal layout for construction sites and this is the ASLS capabilities:

- 1) Utilizing Multi-Objective Optimization (MOO) based on genetic algorithms in order to enable the simultaneous optimization of construction cost, time, safety and environmental concern.
- 2) Minimizing the harmful effect of construction activity on the surrounding neighboring by utilizing an objective function for the environmental concern.
- 3) User friendly interface with huge user interaction in adjusting or adding data and in selecting the desired objective.
- 4) Handled with unlimited number of facilities and project stages.
- 5) Generating 4D dynamic site layouts for actual duration of facilities on the site.
- 6) Representing the site space as a continuous space to allow the facilities to be located anywhere in the construction site (unequal area problems).
- 7) Analyzing any regular or irregular site and facilities shapes.
- 8) Allowing for facilities to orient with angles options according to the user desire.
- 9) Facilities closeness relationship represents the user desire and calculated for the real interaction duration between facilities in site.
- 10) Real distance calculation that represents the actual travel distances between facilities without neglecting the presence of obstruction between them.
- 11) Database library for storing and retrieving construction projects data and the generated optimal solutions.
- 12) Selecting the optimal site layout after generating both entire project layout and stages layout.

It is worth knowing that the aforementioned ASLS capabilities cover all the end user' requirements which measured from the real Egyptian sites as discussed before in chapter 3 and offer a number of new features and functions. The next section will explain in detail the ASLS implementation process.

### **6.3. THE ASLS IMPLEMENTATION PROCESS**

Three steps are required for the implementation process of the ASLS as the following:

#### **Step one: ASLS Access**

Access to the ASLS is done by writing the word (ASLS) in MATLAB command window then pressing on the Enter button in the computer keypad, the ASLS front end window which entitles the full name of the automated system will appear for 5 seconds only as shown in figure (6.1).

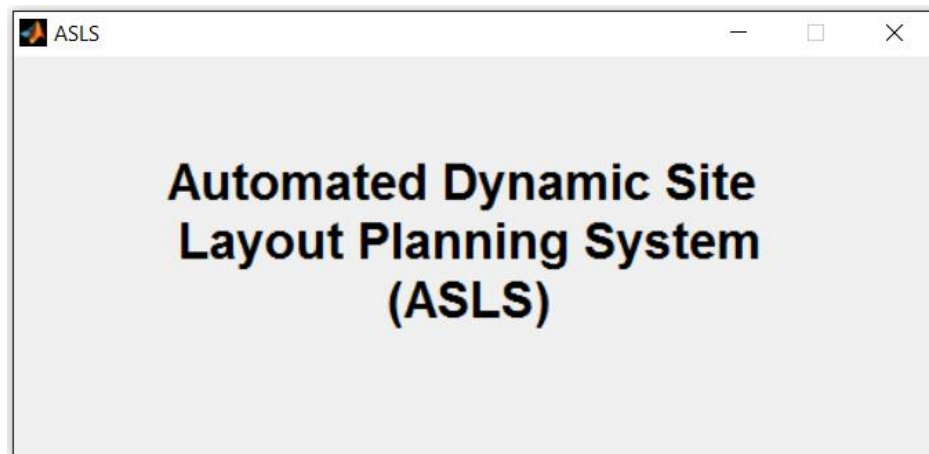


Figure (6. 1): The ASLS front end window.

Then the ASLS main window will appear automatically as shown in figure (6.2).

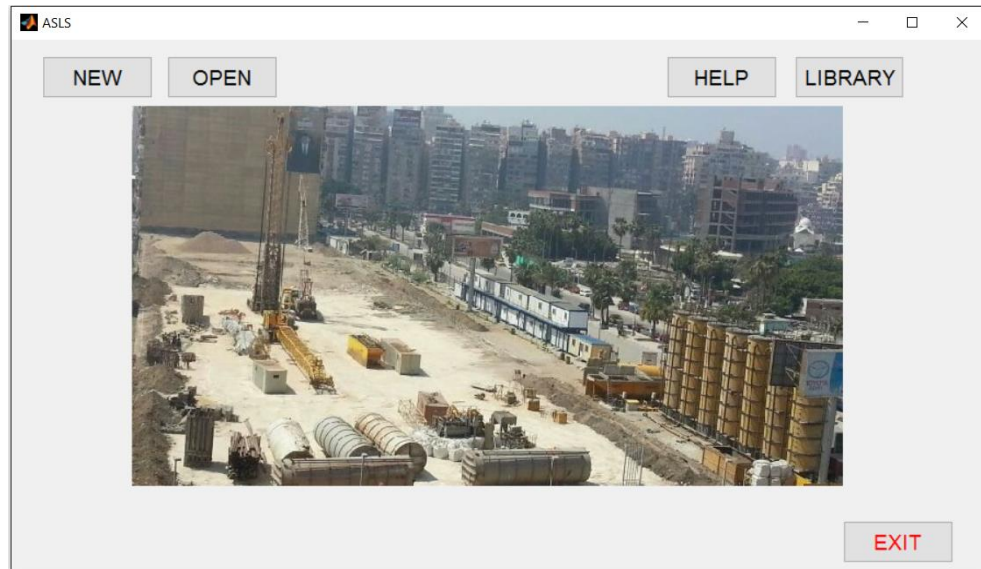


Figure (6. 2): The ASLS main window.

The ASLS main window includes five buttons as follow:

- NEW button for starting a new project as shown in figure (6.2.a).

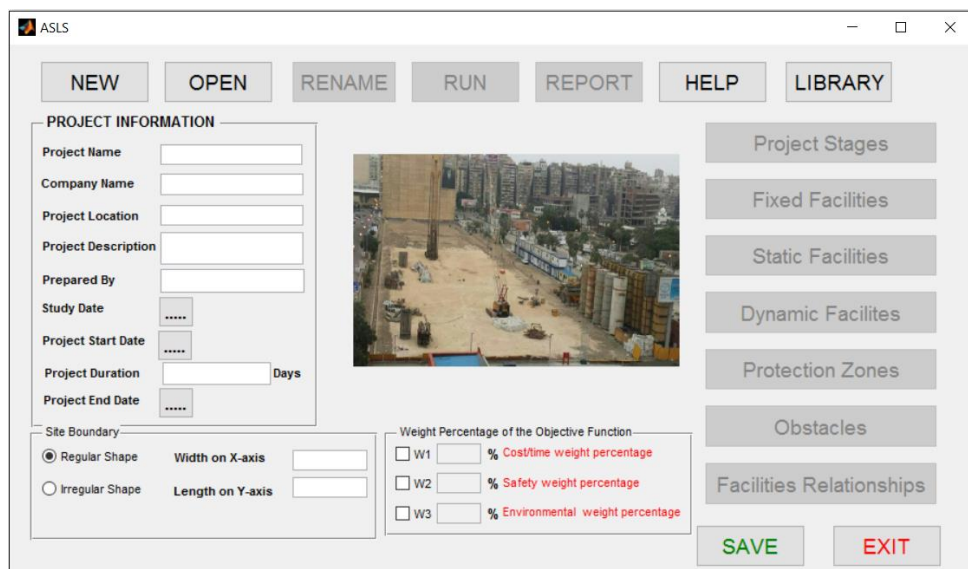


Figure (6. 2. a): New project window.

- OPEN button for selecting and opening a saved project as shown in figure (6.2.b).

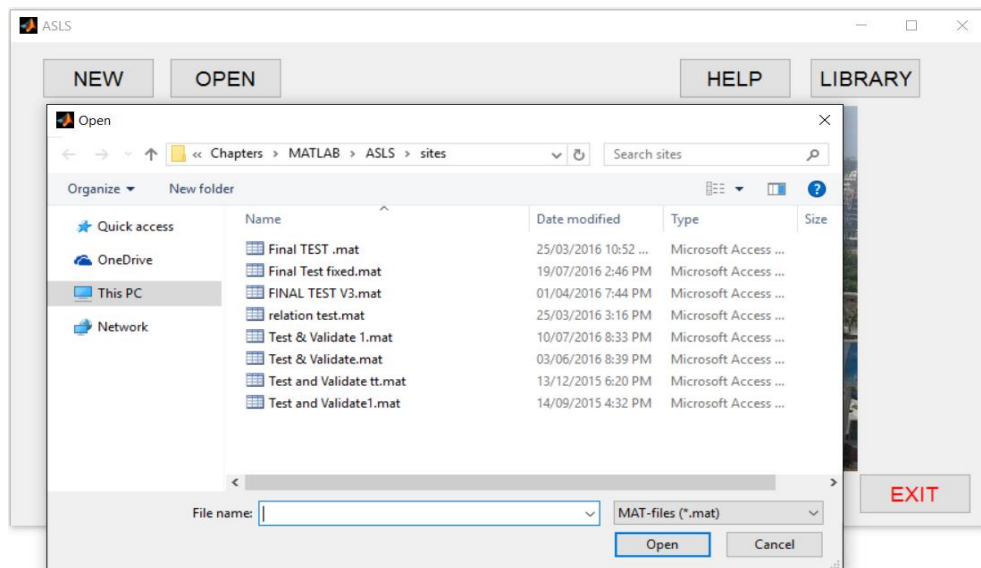


Figure (6. 2. b): Select and open project window.

- HELP button for exploring the ASLS user manual as shown in figure (6.2.c).

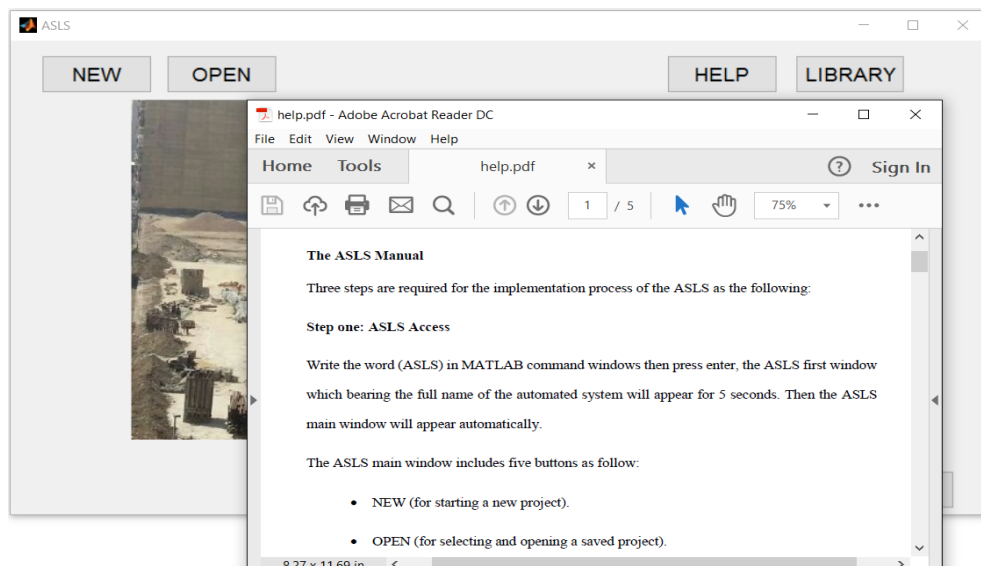


Figure (6. 2. c): Help window.

- LIBRARY button for exploring, entering, editing or deleting the ASLS main database library as shown in figure (6.2.d).

Figure (6. 2. d): The ASLS main database library

- EXIT button for exiting the ASLS as shown in figure (6.2).

### Step two: ASLS Data input or Edit

Input data for a new construction project in the ASLS is done through the NEW window as shown in figure 6.2.a. Three sections should be filled up as follow:

1) project information.

The user should enter the required information which is considered the main information for the examined project. The required information is the project name, company name, project location, project description, study prepared by, project study date, project start date, project duration and project end date.

## 2) site boundary.

The user should select the suitable site boundary shape for the examined project from the two available options which are regular or irregular shape then entering the required information. The required information for the regular shape are the site width on the x-axis and the site length on the y-axis (site width and length should be in meters) according to the required site orientation. While the required information for the irregular shape are the values of the site shape x, y vertices in anti-clockwise order (the user should first enter the all the x vertices then all the y vertices).

## 3) weight percentage of the objective function ( $w_1$ , $w_2$ or $w_3$ ).

The user should enter the required weights percentage ( $w_1$ ,  $w_2$  or  $w_3$ ) for the targeted objective function ( $f_1$ ,  $f_2$  or  $f_3$ ) tradeoff percentage used in generating the layout for the examined project as mentioned before in section 5.2.5.

Then the SAVE button should be pressed to enable the ASLS to store all data inputted. After pressing the SAVE button, a layout for the site boundary will appear on the project window as well as new section and nine new buttons will be activated as shown in figure (6.3).

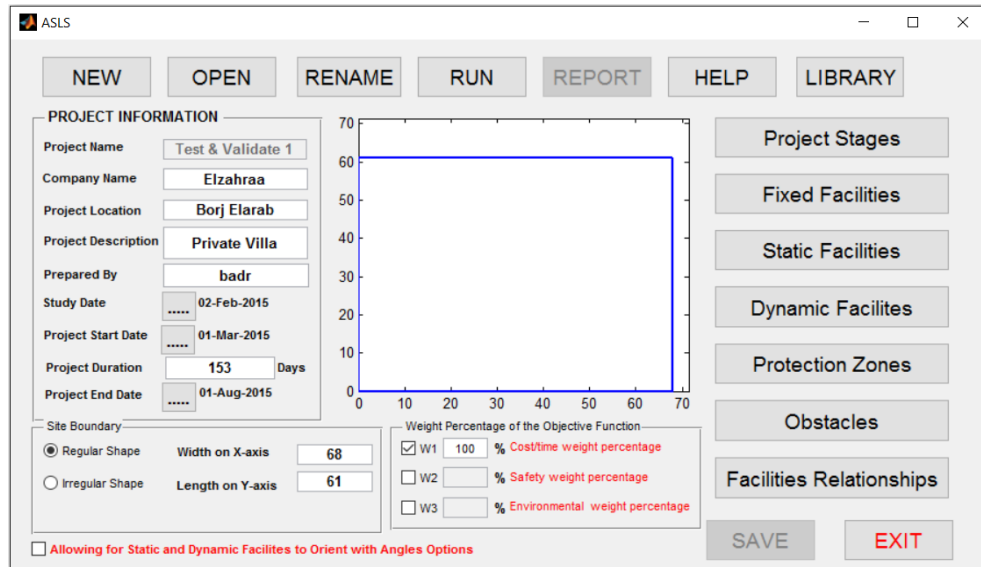


Figure (6. 3): The layout for the site boundary on the project window as well as the new section and the nine new activated buttons.

The new appeared section (Figure 6.3) contains a checkbox that allows for static and dynamic facilities to orient with angles options. By selecting that checkbox, the ASLS will be able to orient the static and dynamic facilities with angles 0 °, 90 °, 180 ° and 270° in the solution search process. Otherwise they will orient as its input shapes.

The nine new activated buttons are:

- RENAME button for changing project's name or save it with other name as shown in figure (6.3.a).

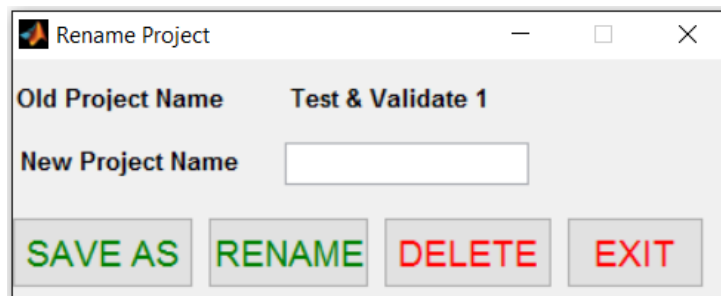


Figure (6.3. a): Rename project window.



- RUN button for running the ASLS as shown in figure (6.3).

Although the RUN button activated in this step, the ASLS will not allow to start the search process for the project optimal site layout until a certain amount of data inputted. These data must include at least two fixed facilities with the closeness relationship between them. If the Run button pressed before inputting these data an error messages appear requesting to input this data first (Figure 6.3.b). After inputting and saving these data, the ASLS will allow starting the search process for the project optimal site layout if the RUN button pressed.

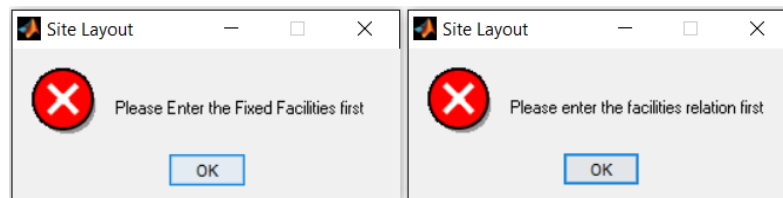


Figure (6.3. b): Examples of error messages when pressing the RUN button before inputting the required data first.

- Project Stages button for entering the project stages' as shown in figure (6.3.c).

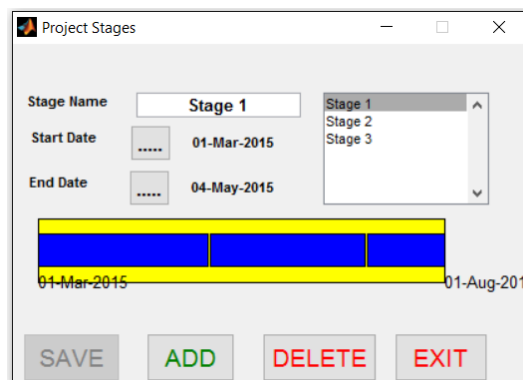


Figure (6.3. c): Project stages window.

- Fixed Facilities button for entering the site fixed facilities' as shown in figure (6.3.d).

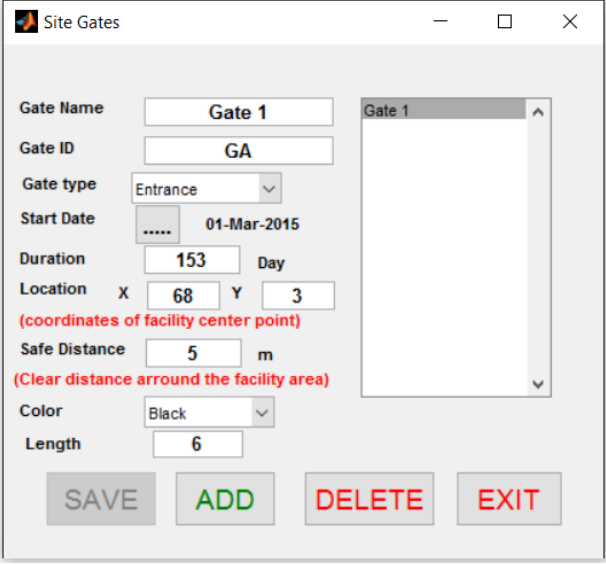
The 'Fixed Facilities' window contains the following elements:

- Facility Name:** Text box with 'Proposed villa 1'.
- Facility ID:** Text box with 'PV'.
- Start Date:** Calendar icon and text box with '01-Mar-2015'.
- Duration:** Text box with '153' and 'Day'.
- Location:** Text boxes for 'X' (30) and 'Y' (41), with a red note '(coordinates of facility center point)' below.
- Hight:** Text box with '8', 'm', and a checked 'with roof' checkbox.
- Orintation:** Text box with '0' and 'Degrees'.
- Safe Distance:** Text box with '0' and 'm', with a red note '(Clear distance around the facility area)' below.
- Color:** Dropdown menu set to 'Blue'.
- Facility Shape:** Radio buttons for 'Regular Shape' (selected) and 'Irregular Shape'.
  - Regular Shape:** 'Width on X-axis' text box with '36'.
  - Irregular Shape:** 'Length on Y-axis' text box with '20'.
- Facilities List:** A list box on the right containing 'Proposed villa 1' (selected) and 'Guard office 1'.
- Buttons:** 'SAVE', 'ADD' (green), 'DELETE' (red), 'EXIT' (red), 'Site Gates', 'Import from Library', and 'Export to Library'.

Figure (6.3. d): Fixed facilities window.

The fixed facilities window includes 3 buttons for:

- i. Site Gates button for entering the site entrance and exit as shown in figure (6.3.d.i).

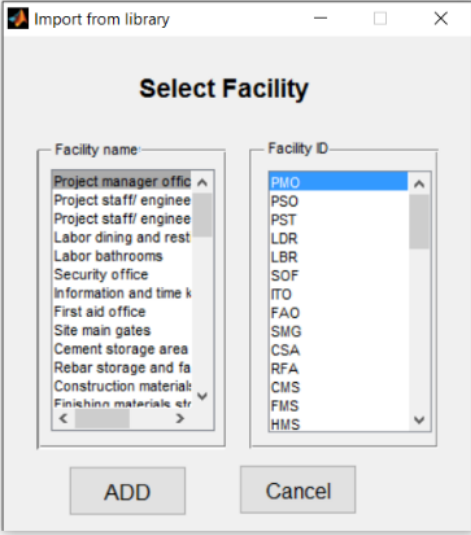


The 'Site Gates' window contains the following fields and controls:

- Gate Name:** Text box with 'Gate 1'.
- Gate ID:** Text box with 'GA'.
- Gate type:** Dropdown menu with 'Entrance' selected.
- Start Date:** Calendar icon and text box with '01-Mar-2015'.
- Duration:** Text box with '153' and a 'Day' label.
- Location:** 'X' text box with '68' and 'Y' text box with '3'. Below these is the text '(coordinates of facility center point)' in red.
- Safe Distance:** Text box with '5' and 'm' label. Below this is the text '(Clear distance around the facility area)' in red.
- Color:** Dropdown menu with 'Black' selected.
- Length:** Text box with '6'.
- Buttons:** 'SAVE' (grey), 'ADD' (green), 'DELETE' (red), and 'EXIT' (red).
- Preview:** A small map area on the right showing 'Gate 1' as a line segment.

Figure (6.3.d. i): Site gates window.

- ii. Import from Library button for exploring and selecting fixed facilities from the ASLS main database library as shown in figure (6.3.d.ii).



The 'Import from library' window features a 'Select Facility' section with two list boxes:

- Facility name:** A list box containing various facility names such as 'Project manager office', 'Project staff/ engineer', 'Labor dining and rest', 'Labor bathrooms', 'Security office', 'Information and time k', 'First aid office', 'Site main gates', 'Cement storage area', 'Rebar storage and fa', 'Construction material', and 'Finishing materials str'.
- Facility ID:** A list box containing abbreviations like 'PMO', 'PSO', 'PST', 'LDR', 'LBR', 'SOF', 'ITO', 'FAO', 'SMG', 'CSA', 'RFA', 'CMS', 'FMS', and 'HMS'.

At the bottom, there are 'ADD' and 'Cancel' buttons.

Figure (6.3.d. ii): Import from library window.

- iii. Export to Library button for adding certain fixed facilities to the ASLS main database library for the possibility of using it in the future.

- Static Facilities button for entering the site static facilities' as shown in figure (6.3.e).

The screenshot shows a software window titled "Static Facilities". It contains several input fields and buttons. On the left, there are fields for "Facility Name" (containing "Project office 1"), "Facility ID" (containing "PO"), "Arrival Date" (containing "01-Mar-2015"), "Duration" (containing "153" with a "Day" unit), "Height" (containing "3" with a "m" unit and a checked "with roof" checkbox), "Safe Distance" (containing "0" with a "m" unit), and "Color" (a dropdown menu set to "Green"). Below these is a "Facility Shape" section with two radio buttons: "Regular Shape" (selected) and "Irregular Shape". The "Regular Shape" section has "Width on X-axis" (4) and "Length on Y-axis" (6) fields. To the right of the input fields is a list box containing "Project office 1", "Mixing area 1", "Steel area 1", "Wood area 1", and "Materials store 1". At the bottom right are "Import from Library" and "Export to Library" buttons. At the bottom are four large buttons: "SAVE", "ADD", "DELETE", and "EXIT". A red text label "(Clear distance around the facility area)" is positioned above the "Color" dropdown.

Figure (6.3. e): Static facilities window.

The static facilities window also includes 2 buttons for importing static facilities from the ASLS main database library or exporting static facilities to the ASLS main database library as mentioned before in fixed facilities (Figure 6.3.d.ii).

- Dynamic Facilities button (for entering the site dynamic facilities' as shown in figure (6.3.f).

The screenshot shows a software window titled "Dynamic Facilities". It contains several input fields and buttons. The fields are: Facility Name (Wood area 2), Facility ID (WA 2), Arrival Date (09-Jun-2015), Duration (45 Day), Relocation Weight (5), Add Dismantling and Erecting Weight (checked, 400), Safe Distance (0 m), Color (Yellow), Height (3 m), and Facility Shape (Regular Shape selected, Width on X-axis 12, Length on Y-axis 6). There are also buttons for Import from Library, Export to Library, SAVE, ADD, DELETE, and EXIT. A red text label "(Clear distance around the facility area)" is visible below the Safe Distance field.

Figure (6.3. f): Dynamic facilities window.

The dynamic facilities window also includes 2 buttons for importing dynamic facilities from the ASLS main database library or exporting dynamic facilities to the ASLS main database library as mentioned before infixed facilities (Figure 6.3.d.ii).

- Protection Zones button for entering the site protection zones' as shown in figure (6.3.g).

Protection zones

Protection Zone Name

Protection Zone ID

Start Date

Location X Y

(coordinates of protection zone center point)

Orintation Degrees

Safe Distance m

(Clear distance arround the protection zone area)

Color Black

Protection Zone Shape

☒ Regular Shape Width on X-axis

☐ Irregular Shape Length on Y axis

SAVE ADD DELETE EXIT

New Protection Zone

Figure (6.3. g): Protection zones window.

- Obstacles button for entering the site obstacles' as shown in figure (6.3.h).

Obstacles

Obstacle Name Tree 1

Obstacle ID TR

Start Date 01-Mar-2015

Duration 153 Day

Location X Y

(coordinates of obstacles center point)

Hight 1 m

Orintation 0 Degree

Safe Distance 0 m

(Clear distance arround the obstacles area)

Color Blue

Obstacles Shape

☒ Regular Shape Width on X-axis 4

☐ Irregular Shape Length on Y-axis 4

SAVE ADD DELETE EXIT

Tree 1

Import from Library

Export to Library

Figure (6.3. h): Obstacles window.

The obstacles window also includes 2 buttons for importing obstacles from the ASLS main database library or exporting obstacles to the ASLS main database library as mentioned before in fixed facilities (Figure 6.3.d.ii).

- Facilities Relationships button for entering the closeness relationships between facilities as shown in figure (6.3.i).

**Facilities Relationships**

**Cost / time closeness relationships** | **Safety concern closeness relationships** | **Environmental concern closeness relationships**

EF MF PF IF TP UP

**Average relationships**

- Please fill the relations between facilities with average weights that express the six governing factors or fill each governing factors separately.  
 - Please fill the relations between facilities with a 9-point scale.  
 - 9 indicate a significant relationship between two facilities and they should be assigned as close as possible.  
 - 0 indicates that facilities should be assigned far away from each other.

	Wood area 2	Materials store 1	Wood area 1	Steel area 1	Mixing area 1	Project office 1	Gate 1	Guard office 1
Proposed villa 1	9	9	9	9	9	0	0	0
Guard office 1	0	0	0	0	2	0	0	0
Gate 1	0	0	0	0	0	0	0	0
Project office 1	0	0	0	0	0	0	0	0
Mixing area 1	0	0	0	0	0	0	0	0
Steel area 1	0	0	0	0	0	0	0	0
Wood area 1	0	0	0	0	0	0	0	0
Materials store 1	0	0	0	0	0	0	0	0

Clear SAVE EXIT

Figure (6.3. i): Facilities relationships window.

The facilities relationships window includes 3 buttons for:

- i. Cost/time closeness relationships button for entering the average cost/time closeness relationships or the six governing factors that set the average cost/time closeness relationships between facilities.
- ii. Safety closeness relationships button for entering the safety closeness relationships between facilities.

- iii. Environmental concern closeness relationships button for entering the environmental concern closeness relationships between facilities and protection zones. This button activated only if there is a data inputted for the protection zone.

In case of any errors or incomplete data happened during inputting data to the ASLS, error and alert messages will appear automatically to draw attention to the problem occurred as shown in figure (6.4).

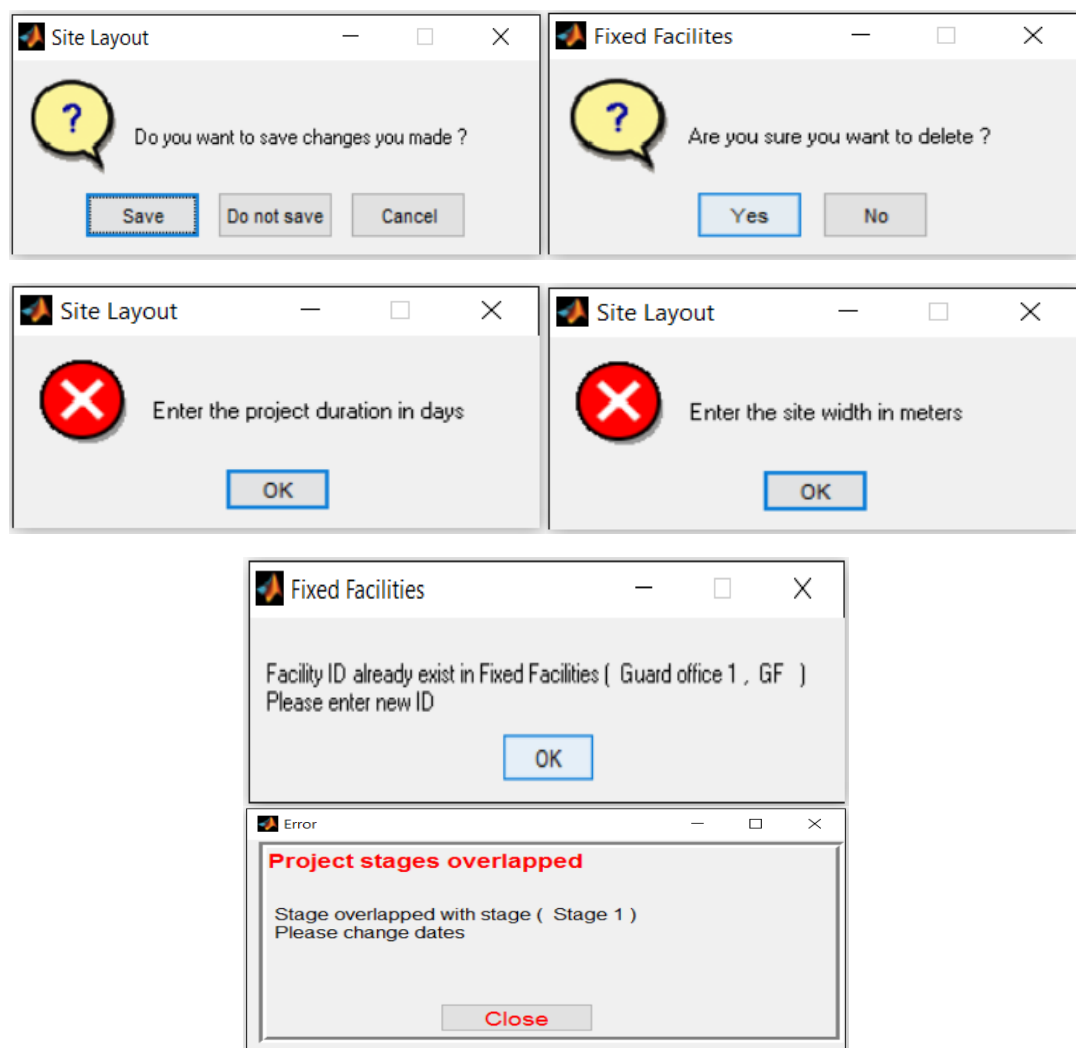


Figure (6. 4): Examples of error and alert messages that appear automatically to draw attention to any problem occurred.



Editing data for the saved construction projects in the ASLS is done through the OPEN window as shown in figure (6.2.b) by selecting the project and edit the required data then pressing on the SAVE button (Figure 6.5).

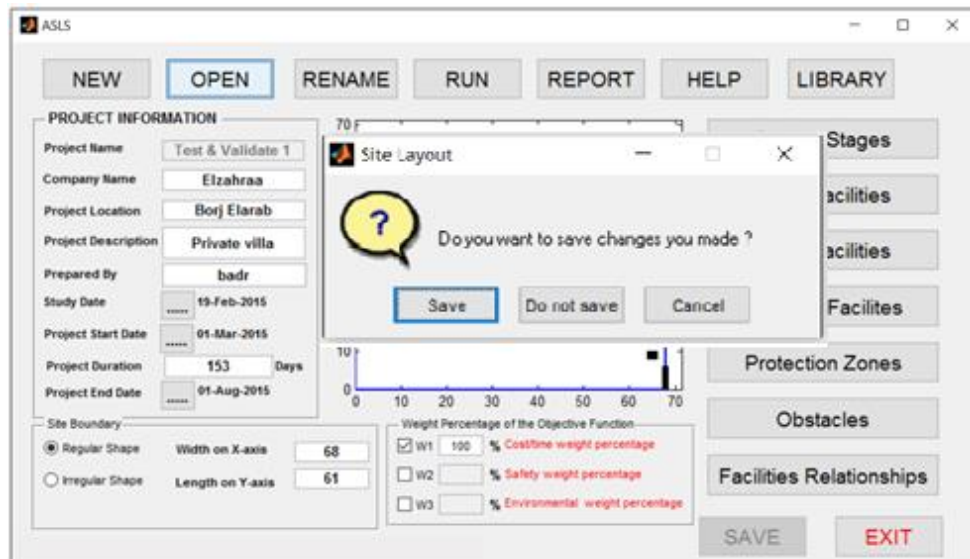


Figure (6. 5): Examples of editing and saving data.

After finishing step 1 and 2 (the ASLS access and the ASLS data input), the SAVE button should be pressed. Accordingly, the ASLS is ready for step three where the search process for the optimal site layout solution is implemented. This will be explained in the next section.

### Step three: ASLS Run

Starting the search process for the optimal site layout solution is done by pressing the RUN button as shown in figure (6.3). While the ASLS implements the search process a temporary window will appear, this window demonstrates the change of solution score with the GA generation (Figure 6.6).

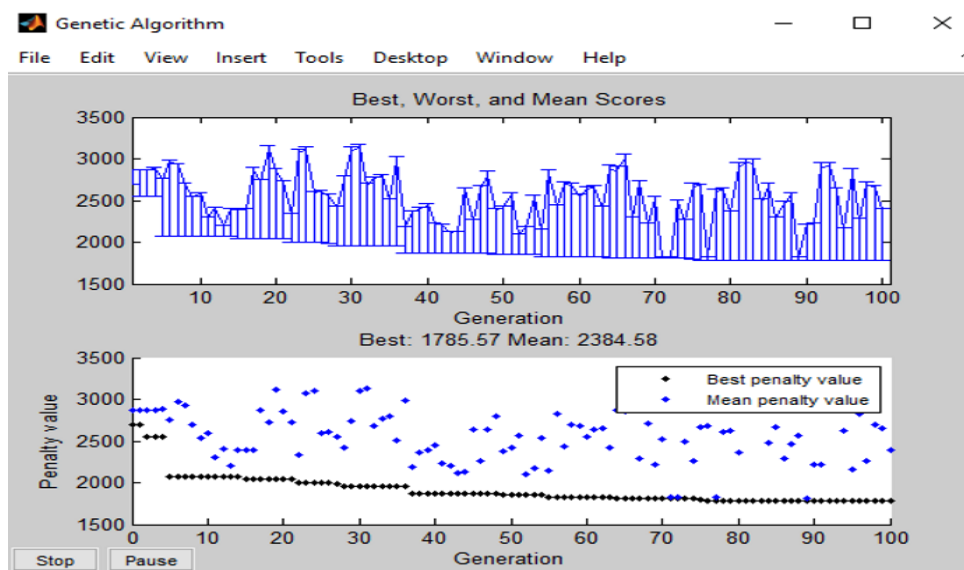


Figure (6. 6): Changing of solution score with the GA generation.

For the projects that include stages, a separate layout window for the generated entire project layout appears when the search process for step one finished. Adding to that, separate layout windows for the generated project stages layouts appear when the search process for each stage finished. Otherwise projects do not include stages, a separate layout window for the generated entire project layout only appears when the search process finished (Figure 6.7).

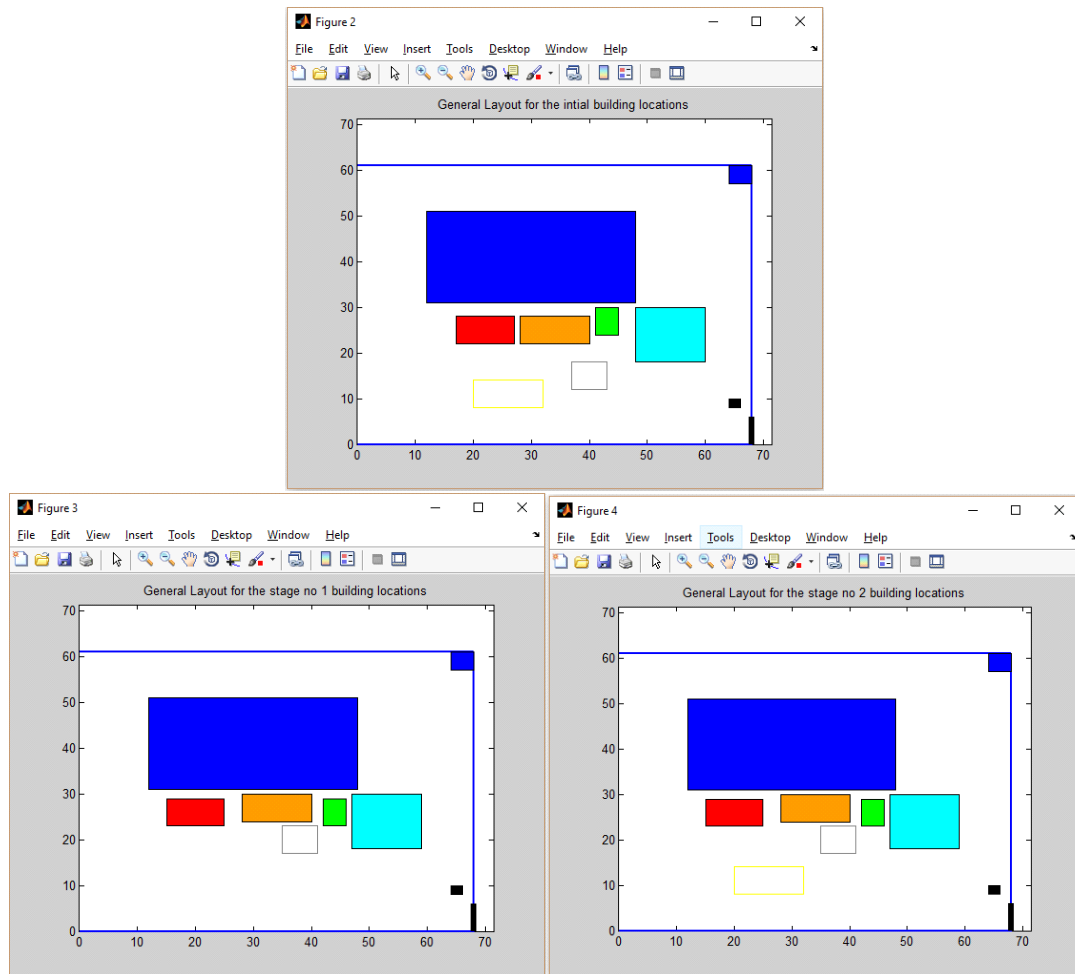


Figure (6. 7): The separate layout window/windows that generated during the search process depends on project that includes stages or not.

When the ASLS finished the search process, the GA temporary window will only disappear automatically and the following will appear:

- A solution report window which contains detailed report for the optimal solution generated by ASLS will appeared (Figure 6.8).

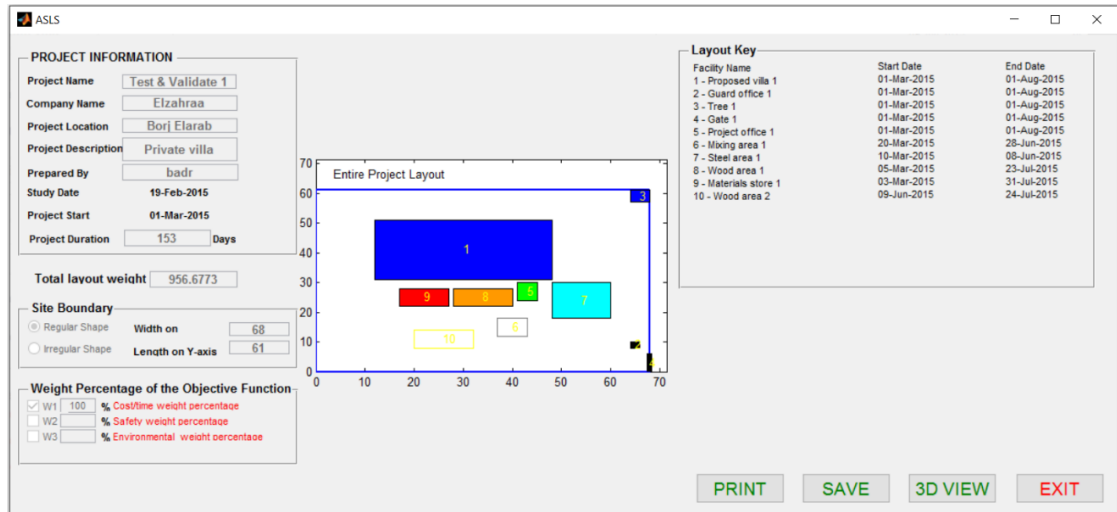


Figure (6. 8): The solution report window.

The solution report window includes 4 buttons (Figure 6.8):

- i. PRINT button for printing the solution report.
- ii. SAVE button for saving the solution report.
- iii. 3D VIEW button for exploring the site layout in 3D view (Figure 6.8.a).

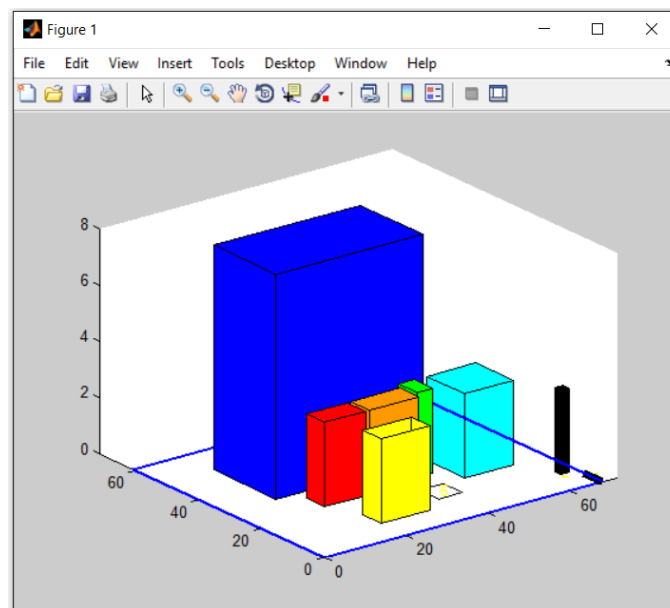
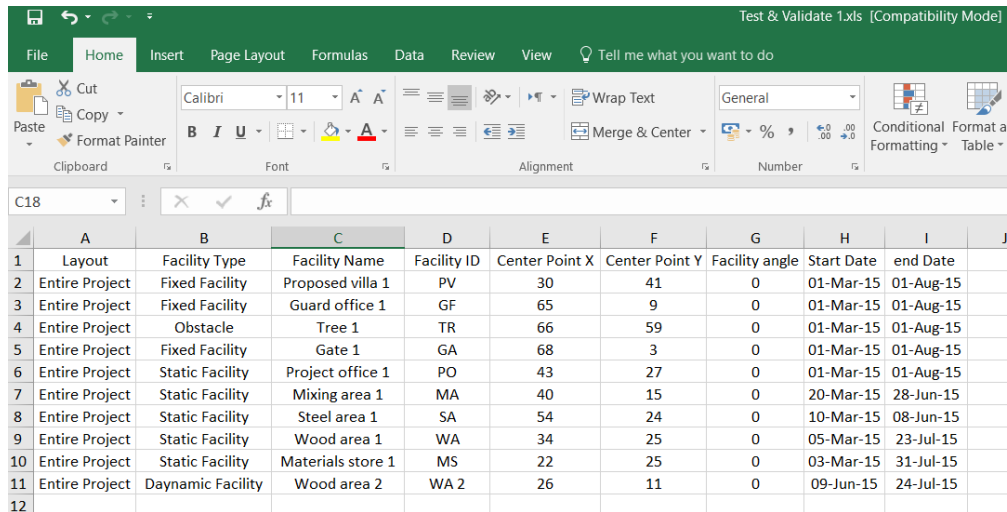


Figure (6.8. a): 3D view for the generated layout.

iv. EXIT button for exiting from the solution report window.

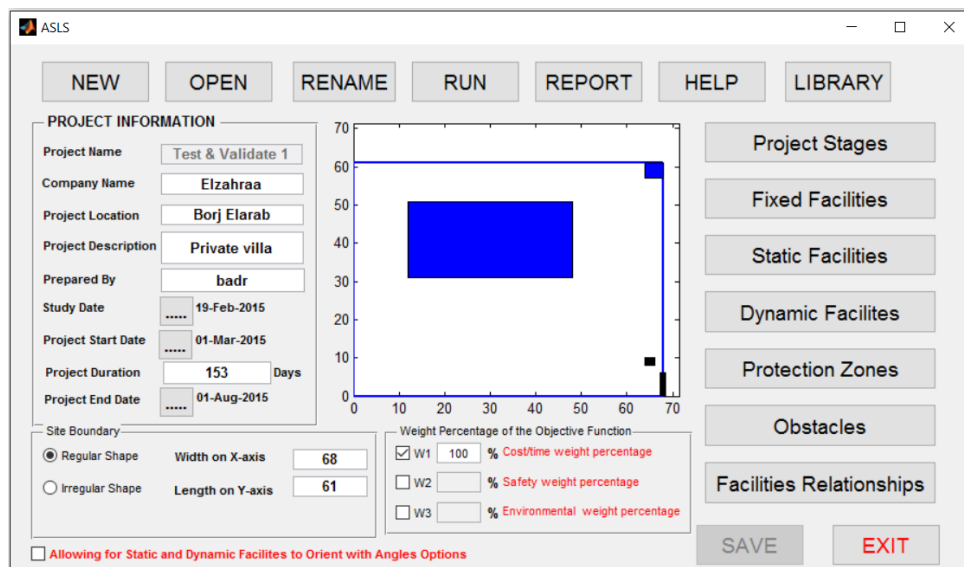
- An Excel sheet that contains main data for the site facilities included in the search process as shown in figure (6.9).



	A	B	C	D	E	F	G	H	I
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date
2	Entire Project	Fixed Facility	Proposed villa 1	PV	30	41	0	01-Mar-15	01-Aug-15
3	Entire Project	Fixed Facility	Guard office 1	GF	65	9	0	01-Mar-15	01-Aug-15
4	Entire Project	Obstacle	Tree 1	TR	66	59	0	01-Mar-15	01-Aug-15
5	Entire Project	Fixed Facility	Gate 1	GA	68	3	0	01-Mar-15	01-Aug-15
6	Entire Project	Static Facility	Project office 1	PO	43	27	0	01-Mar-15	01-Aug-15
7	Entire Project	Static Facility	Mixing area 1	MA	40	15	0	20-Mar-15	28-Jun-15
8	Entire Project	Static Facility	Steel area 1	SA	54	24	0	10-Mar-15	08-Jun-15
9	Entire Project	Static Facility	Wood area 1	WA	34	25	0	05-Mar-15	23-Jul-15
10	Entire Project	Static Facility	Materials store 1	MS	22	25	0	03-Mar-15	31-Jul-15
11	Entire Project	Daynamic Facility	Wood area 2	WA 2	26	11	0	09-Jun-15	24-Jul-15
12									

Figure (6. 9): The Excel sheet that contains main data for the site facilities included in the search process.

Furthermore, the REPORT button in the project window will be activated to retrieve the solution report for the examined project any time (Figure 6.10).



ASLS

NEW OPEN RENAME RUN REPORT HELP LIBRARY

**PROJECT INFORMATION**

Project Name: Test & Validate 1  
 Company Name: Elzahraa  
 Project Location: Borj Elarab  
 Project Description: Private villa  
 Prepared By: badr  
 Study Date: 19-Feb-2015  
 Project Start Date: 01-Mar-2015  
 Project Duration: 153 Days  
 Project End Date: 01-Aug-2015

Site Boundary:  
☒ Regular Shape Width on X-axis: 68  
☐ Irregular Shape Length on Y-axis: 61

Weight Percentage of the Objective Function:  
☒ W1 100 % Cost/time weight percentage  
☐ W2 % Safety weight percentage  
☐ W3 % Environmental weight percentage

☐ Allowing for Static and Dynamic Facilities to Orient with Angles Options

Project Stages  
 Fixed Facilities  
 Static Facilities  
 Dynamic Facilites  
 Protection Zones  
 Obstacles  
 Facilities Relationships

SAVE EXIT

Figure (6. 10): The activated REPORT button.

This section explained in detail the ASLS implementation process, the next section will clarify how the ASLS will facilitate the site layout planning work for users who are new to the Egyptian practice used in the Egyptian sites.

#### **6.4. DATA BASE FOR EGYPTIAN SITES**

This section demonstrates how the ASLS will facilitate the site layout planning work in the Egyptian sites for users (international and local users). The ASLS main database library contains the most sixteen repetitive facilities with their sizes and closeness relations which measured from the real Egyptian sites as discussed before in chapter 3. These sixteen facilities cannot be deleted from the ASLS main database library but it can be modified according to user desire. The ASLS users can use this database directly or take it as a guide to work in Egyptian sites. The next section will illustrate the results of genetic algorithms tuning process.

#### **6.5. TUNING OF GENETIC ALGORITHMS PARAMETERS**

To illustrate the effect of genetic algorithms parameters on the performance of the genetic algorithms optimization process, a tuning process for the default values of these parameters conducted through hypothetical construction site. An ASLS run executed for each change to the value of these parameters to achieve the best parameters values that generate the optimal solutions. Table (6.1) presents the best values for the genetic algorithms parameters resulting from the tuning process.

Furthermore, the fixed number of generation reached and the value of solutions or best-so-far solution fluctuates within a small defined range whichever takes place first will both be used as a termination conditions to end the optimization process. The next section will illustrate the details of the ASLS validation process through two construction projects based in Egypt as two case studies.

Table (6. 1): The values of the genetic algorithms parameters.

Parameter	Value
Generations	100
Population type	Doublevector
Population size	100
Selection function	@selectionstochunif
Mutation function	@mutationadaptfeasible
Crossover function	@crossovertwopoint
Crossover fraction	0.7
TimeLimit	Inf

## 6.6. THE ASLS VALIDATION

The ASLS validation process will execute through a simulation experiment on two construction projects based in Egypt as two case studies to examine the ASLS accuracy and effectiveness as mentioned before in section 4.5. The ASLS will be validated through each case study by three trials to test the ASLS calculation accuracy as well as performance and capabilities effectiveness. The simulation experiment data collection is done using observations method. observations will be used to check, verify and compare the results of the ASLS solutions to the results of the real solutions executed in both case studies. The analysis of observed results will complete based on the results comparison as mentioned before in section 4.6.

Due to the construction projects scope and layouts execution method in Egypt (which only consider for the project cost/time and the Euclidean distance), the ASLS validation process will be executed based on project cost/time minimization scenario only (first objective function,  $f_1$ ) In addition, the ASLS will be programmed to consider the Euclidean distance as the actual travel distances between the site facilities

instead of real distance. The simulation experiment through both case studies are described in detail in the following sections together with the findings.

### 6.6.1. Case Study 1

The simulation experiment first case study is used to validate the ASLS. It will be a small-scale project. The project is a private residential villa of area 720 m<sup>2</sup>, while the total area of the site including the proposed villa is 4148 m<sup>2</sup> as shown in figure (6.11).

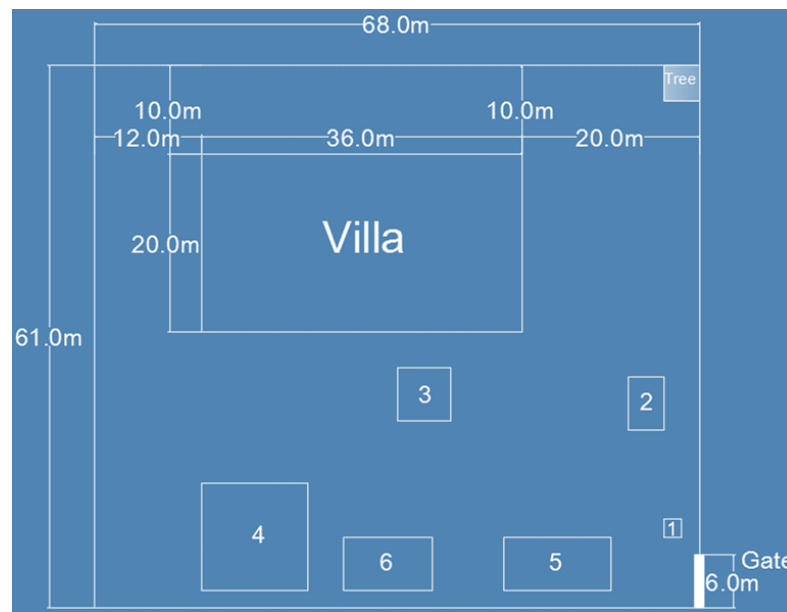


Figure (6. 11): The original site layout developed by The project's manager.

This site is located in Borg El Arab, Alexandria, Egypt and includes six facilities as well as the proposed villa, site gate and one obstacle as shown in table (6.2). The project's budget= 1.5 million EGP. The project's start date is the 1<sup>st</sup> of March 2015 and end on the 1<sup>st</sup> of August 2015, the project duration is 153 days.



Table (6. 2): The project's facilities data.

No.	Facility Name	Facility I.D.	Facility Type	Facility Size (W*L*H) in meters	Center Point	Start Date	End Date	Duration (Days)
1	Guard Office	GO	Fixed Facility	2*2*3	65,9	01/03/2015	1/08/2015	153
2	Project Office	PO	Fixed Facility	4*6*3	62,23	01/03/2015	1/08/2015	153
3	Mixing Area	MA	Fixed Facility	6*6*3	37,23	20/03/2015	1/08/2015	100
4	Steel Area	SA	Fixed Facility	12*12*3	18,8	10/03/2015	1/08/2015	90
5	Wood Area	WA	Fixed Facility	12*6*3	50,5	05/03/2015	1/08/2015	140
6	Materials Store	MS	Fixed Facility	10*6*3	33,5	03/03/2015	1/08/2015	150
7	Proposed Villa	PV	Fixed Facility	36*20*8	30,41	01/03/2015	1/08/2015	153
8	Tree	TR	Obstacles	4*4*3	66,59	01/03/2015	1/08/2015	153
9	Gate	GT	Fixed Facility	6*0*0	66,3	01/03/2015	1/08/2015	153

Figure (6.11) has shown the site layout developed by the project's manager based on his own experience in order to minimize the overall project's cost and time. This site layout will be used for validating the ASLS, so the project's manager is assigned to identify the cost and time closeness relationship weights between the required facilities in order to be used in the ASLS optimal site layout search process (Table 6.3).

Table (6. 3): The cost and time closeness relationship weights between the project facilities that are identified by the project's manager.

Facility name/number	Materials Store	Wood Area	Steel Area	Mixing Area	Project Office	Guard Office	Gate
Proposed villa	9	9	9	9	9	0	0
Gate	4	4	4	4	4	9	
Guard Office	0	0	0	0	2		
Project Office	5	5	5	5			
Mixing Area	9	0	0				
Steel Area	0	0					
Wood Area	0						

The ASLS will be validated through this case by three trials. The first trial is setup for validating the ASLS accuracy while the other two trials are setup for validating the ASLS effectiveness as follow:

a. Trial #1

In this trial the ASLS will be validated for its calculations accuracy not for generating an optimal site layout, by inputting the project data mentioned above and the project facilities data (Table 6.2) same as the case study data as shown in figures (6.12; 6.12.a; 6.12.b; and 6.12.c).

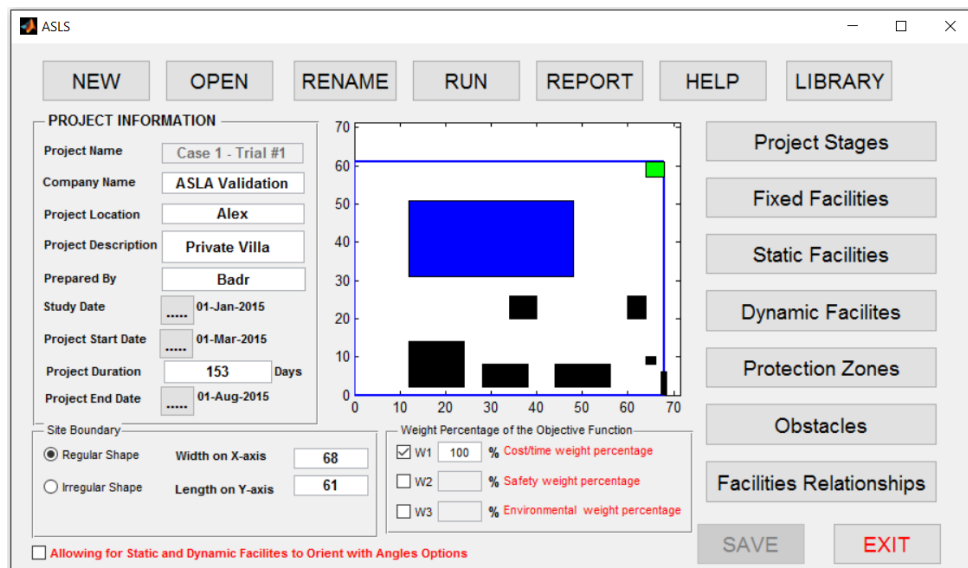


Figure (6. 12): Project data inputted to the ASLS for trial #1.

Figure (6.12.a) shows the site facilities after inputted to the ASLS as fixed facilities only.

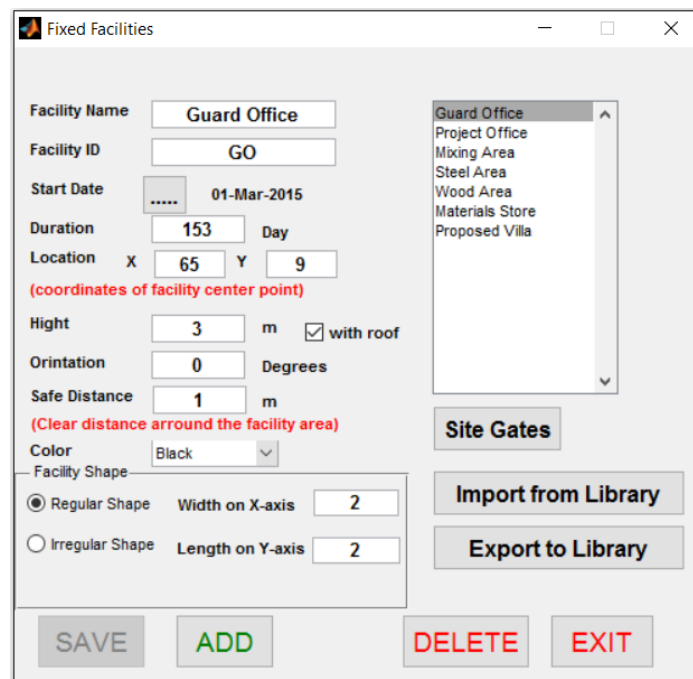


Figure (6.12. a): The fixed facilities data.

Figure (6.12.b) shows the obstacles facilities after inputted in the ASLS.

Obstacles

Obstacle Name:

Obstacle ID:

Start Date:

Duration:  Day

Location X:  Y:   
(coordinates of obstacles center point)

Height:  m

Orientation:  Degree

Safe Distance:  m  
(Clear distance around the obstacles area)

Color:

Obstacles Shape:

☒ Regular Shape Width on X-axis:

☐ Irregular Shape Length on Y-axis:

Figure (6.12. b): The obstacles facilities data.

Figure (6.12.c) shows the relationship weights between the project facilities after inputted in the ASLS.

Facilities Relationships

**Cost / time closeness relationships** | Safety concern closeness relationships... | Environmental concern closeness relationships...

EF MF PF IF TP UP

**Average relationships**

- Please fill the relations between facilities with average weights that express the six governing factors or fill each governing factors separately.  
- Please fill the relations between facilities with a 9-point scale.  
- 9 indicate a significant relationship between two facilities and they should be assigned as close as possible.  
- 0 indicates that facilities should be assigned far away from each other.

	Gate 1	Proposed Villa	Materials Store	Wood Area	Steel Area	Mixing Area	Project Office
Guard Office	9	0	0	0	0	0	2
Project Office	4	9	5	5	5	5	0
Mixing Area	4	9	9	0	0	0	0
Steel Area	4	9	0	0	0	0	0
Wood Area	4	9	0	0	0	0	0
Materials Store	4	9	0	0	0	0	0
Proposed Villa	0	0	0	0	0	0	0

Figure (6.12. c): The relationship weights between the project facilities.

After finishing the project data inputting, the ASLS will be used to calculate the overall layout weight of the original facilities locations by pressing the REPORT button. The solution report windows will appear (Figures 6.13; 6.13.a; and 6.14), the calculated layout weight by the ASLS should be equal to the manually calculated – by Excel sheet (Microsoft Corporation, 2013) – layout weight for the original layout (Figure 6.15) in order to prove the calculations accuracy of the ASLS. In this trial the ASLS is validated for the calculations accuracy only without any optimization search process for new facilities location as they are all inputted as fixed facilities only.

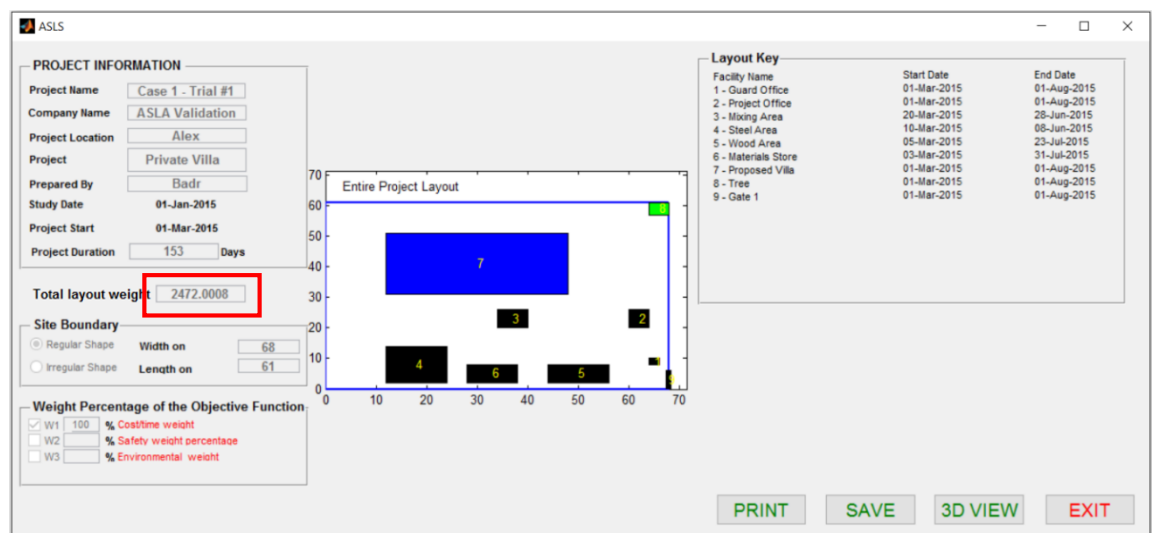


Figure (6. 13): The solution report for trial #1.

The calculated layout weight by the ASLS for the original facilities locations=2472.0008.

Figure (6.13.a) shows a 3D view for the original layout developed by the ASLS.

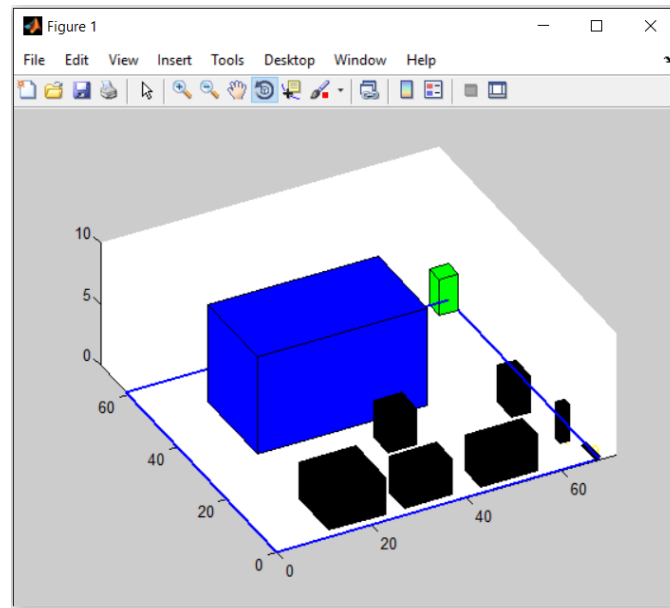


Figure (6.13. a): 3D view for the original layout developed by the ASLS

Figure (6.14) shows the Excel sheet generated with the solution report that contains main data for the site facilities.

Case 1 - Trial #1.xls [Compatibility Mode] - Excel									
File Home Insert Page Layout Formulas Data Review View Tell me what you want to do									
<div> <div>Clipboard</div> <div>Font</div> <div>Alignment</div> <div>Number</div> <div>Conditional Formatting</div> <div>Table</div> </div>									
	A	B	C	D	E	F	G	H	I
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date
2	Entire Project	Fixed Facility	Guard Office	PV	65	9	0	01-Mar-15	01-Aug-15
3	Entire Project	Fixed Facility	Project Office	GO	62	23	0	01-Mar-15	01-Aug-15
4	Entire Project	Fixed Facility	Mixing Area	MS	37	23	0	20-Mar-15	28-Jun-15
5	Entire Project	Fixed Facility	Steel Area	SA	18	8	0	10-Mar-15	08-Jun-15
6	Entire Project	Fixed Facility	Wood Area	WA	50	5	0	05-Mar-15	23-Jul-15
7	Entire Project	Fixed Facility	Materials Store	MS	33	5	0	03-Mar-15	31-Jul-15
8	Entire Project	Fixed Facility	Proposed Villa	PV	30	41	0	01-Mar-15	01-Aug-15
9	Entire Project	Obstacle	Tree	TR	66	59	0	01-Mar-15	01-Aug-15
10	Entire Project	Fixed Facility	Gate 1	GT	68	3	0	01-Mar-15	01-Aug-15

Figure (6. 14): The Excel sheet generated with the solution report.

Figure (6.15) shows to the manual calculation – by Excel sheet – for the total weight of the original layout.

Clipboard

Font

Alignment

AP10

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Manual Calculation Sheet																	
2						Distance		Relation										
3	Guard O	65	3	Guard O	65	3		0		0			Total Layout weight 2472.0008					
4	Project C	62	23	Guard O	65	3		2		28.64								
5	Mixing A	37	23	Guard O	65	3		0		0								
6	Steel Ari	18	8	Guard O	65	3		0		0								
7	Wood A	50	5	Guard O	65	3		0		0								
8	Material	33	5	Guard O	65	3		0		0								
9	Propose	30	41	Guard O	65	3		0		0								
10	Gate 1	68	3	Guard O	65	3		3		60.37								
11	Guard O	65	3	Project C	62	23		0		0								
12	Project C	62	23	Project C	62	23		0		0								
13	Mixing A	37	23	Project C	62	23		3.268		81.7								
14	Steel Ari	18	8	Project C	62	23		2.941		136.7								
15	Wood A	50	5	Project C	62	23		4.575		38.38								
16	Material	33	5	Project C	62	23		4.902		167.3								
17	Propose	30	41	Project C	62	23		3		330.4								
18	Gate 1	68	3	Project C	62	23		4		83.52								
19	Guard O	65	3	Mixing A	37	23		0		0								
20	Project C	62	23	Mixing A	37	23		0		0								
21	Mixing A	37	23	Mixing A	37	23		0		0								
22	Steel Ari	18	8	Mixing A	37	23		0		0								
23	Wood A	50	5	Mixing A	37	23		0		0								
24	Material	33	5	Mixing A	37	23		5.882		108.5								
25	Propose	30	41	Mixing A	37	23		5.882		113.6								
26	Gate 1	68	3	Mixing A	37	23		2.614		96.45								
27	Guard O	65	3	Steel Ari	18	8		0		0								
28	Project C	62	23	Steel Ari	18	8		0		0								
29	Mixing A	37	23	Steel Ari	18	8		0		0								
30	Steel Ari	18	8	Steel Ari	18	8		0		0								
31	Wood A	50	5	Steel Ari	18	8		0		0								
32	Material	33	5	Steel Ari	18	8		0		0								
33	Propose	30	41	Steel Ari	18	8		5.294		185.3								
34	Gate 1	68	3	Steel Ari	18	8		2.353		118.2								
35	Guard O	65	3	Wood A	50	5		0		0								
36	Project C	62	23	Wood A	50	5		0		0								
37	Mixing A	37	23	Wood A	50	5		0		0								
38	Steel Ari	18	8	Wood A	50	5		0		0								
39	Wood A	50	5	Wood A	50	5		0		0								
40	Material	33	5	Wood A	50	5		0		0								
41	Propose	30	41	Wood A	50	5		8.235		339.2								
42	Gate 1	68	3	Wood A	50	5		3.66		66.29								
43	Guard O	65	3	Material	33	5		0		0								
44	Project C	62	23	Material	33	5		0		0								
45	Mixing A	37	23	Material	33	5		0		0								
46	Steel Ari	18	8	Material	33	5		0		0								
47	Wood A	50	5	Material	33	5		0		0								
48	Material	33	5	Material	33	5		0		0								
49	Propose	30	41	Material	33	5		8.824		318.7								
50	Gate 1	68	3	Material	33	5		3.922		137.5								
51	Guard O	65	3	Propose	30	41		0		0								
52	Project C	62	23	Propose	30	41		0		0								
53	Mixing A	37	23	Propose	30	41		0		0								
54	Steel Ari	18	8	Propose	30	41		0		0								
55	Wood A	50	5	Propose	30	41		0		0								
56	Material	33	5	Propose	30	41		0		0								
57	Propose	30	41	Propose	30	41		0		0								
58	Gate 1	68	3	Propose	30	41		0		0								
59	Guard O	65	3	Gate 1	68	3		0		0								
60	Project C	62	23	Gate 1	68	3		0		0								
61	Mixing A	37	23	Gate 1	68	3		0		0								
62	Steel Ari	18	8	Gate 1	68	3		0		0								
63	Wood A	50	5	Gate 1	68	3		0		0								
64	Material	33	5	Gate 1	68	3		0		0								
65	Propose	30	41	Gate 1	68	3		0		0								
66	Gate 1	68	3	Gate 1	68	3		0		0								

Figure (6. 15): The manual calculation – by Excel sheet – for the total layout weight of the original layout.

The manually calculated layout weight by the Excel sheet for the original site layout= 2472.0008.

By comparing the results from the ASLS and Manual calculations, the results are quite similar. This means that the ASLS acts accurately in weight calculation.

Due to the changing in the facilities type's in trials two and three, the facilities numbering will change in the ASLS solution report according to the method that the ASLS involved them in the search process (fixed facilities, obstacles, site gates, protection zones, static facilities then dynamic facilities).

b. Trial #2

In this trial the ASLS will be validated for its effectiveness by generating an optimal site layout for the examined case study during the entire project duration with the incorporation of static facilities in the search process. The weight of the generated layout will be compared with the weight of original site layout and supposed to have less weight in order to prove the ASLS effectiveness. The project data and the project facilities data (Table 6.4) will be inputted again but this time the Project Office, Mixing Area, Steel Area, Wood Area and Materials Store facilities inputted as static facilities (Figures 6.16; and 6.16. a).



Table (6. 4): The project's facilities data for Trial #2.

No.	Facility Name	Facility I.D.	Facility Type	Facility Size (W*L*H) in meters	Center Point	Start Date	End Date	Duration (Days)
1	Guard Office	GO	Fixed Facility	2*2*3	65,9	01/03/2015	1/08/2015	153
2	Project Office	PO	Static Facility	4*6*3	--	01/03/2015	1/08/2015	153
3	Mixing Area	MA	Static Facility	6*6*3	--	20/03/2015	1/08/2015	100
4	Steel Area	SA	Static Facility	12*12*3	--	10/03/2015	1/08/2015	90
5	Wood Area	WA	Static Facility	12*6*3	--	05/03/2015	1/08/2015	140
6	Materials Store	MS	Static Facility	10*6*3	--	03/03/2015	1/08/2015	150
7	Proposed Villa	PV	Fixed Facility	36*20*8	30,41	01/03/2015	1/08/2015	153
8	Tree	TR	Obstacles	4*4*3	66,59	01/03/2015	1/08/2015	153
9	Gate	GT	Fixed Facility	6*0*0	66,3	01/03/2015	1/08/2015	153

Figure (6.16): shows the project data for trial # 2.

The ASLS Project Information window displays the following data for trial #2:

- Project Name:** Case 1 - Trial #2
- Company Name:** ASLS Validation
- Project Location:** Borj Elarab
- Project Description:** Private villa
- Prepared By:** badr
- Study Date:** 19-Feb-2015
- Project Start Date:** 01-Mar-2015
- Project Duration:** 153 Days
- Project End Date:** 01-Aug-2015

**Site Boundary:**

- ☒ Regular Shape: Width on X-axis: 68, Length on Y-axis: 61
- ☐ Irregular Shape

**Weight Percentage of the Objective Function:**

- ☒ W1: 100 % Cost/time weight percentage
- ☐ W2: % Safety weight percentage
- ☐ W3: % Environmental weight percentage

☐ Allowing for Static and Dynamic Facilities to Orient with Angles Options

**Facilities Relationships:**

- Project Stages
- Fixed Facilities
- Static Facilities
- Dynamic Facilities
- Protection Zones
- Obstacles

**Buttons:** NEW, OPEN, RENAME, RUN, REPORT, HELP, LIBRARY, SAVE, EXIT

Figure (6. 16): Project data inputted to the ASLS for trial #2.

Figure (6.16.a): shows the site facilities which inputted as static facilities for trial # 2.

The Static Facilities window displays the following data for the Project office:

- Facility Name:** Project office
- Facility ID:** PO
- Arrival Date:** 01-Mar-2015
- Duration:** 153 Day
- Hight:** 3 m
- Safe Distance:** 0 m
- Color:** Green
- Facility Shape:**
  - ☒ Regular Shape: Width on X-axis: 4, Length on Y-axis: 6
  - ☐ Irregular Shape

**Facilities List:**

- Project office
- Mixing area
- Steel area
- Wood area
- Materials store

**Buttons:** Import from Library, Export to Library, SAVE, ADD, DELETE, EXIT

Figure (6.16. a): The static facilities data.

After finishing the project data inputting, the ASLS will be used to locate an optimal space for the inputted static facilities through a GA optimization search process by pressing the RUN button. After the ASLS finishes the search process, the solution report window appears and the generated layout obtains a total layout weight = 1785.5657 (Figures 6.17; 6.17.a; and 6.18).

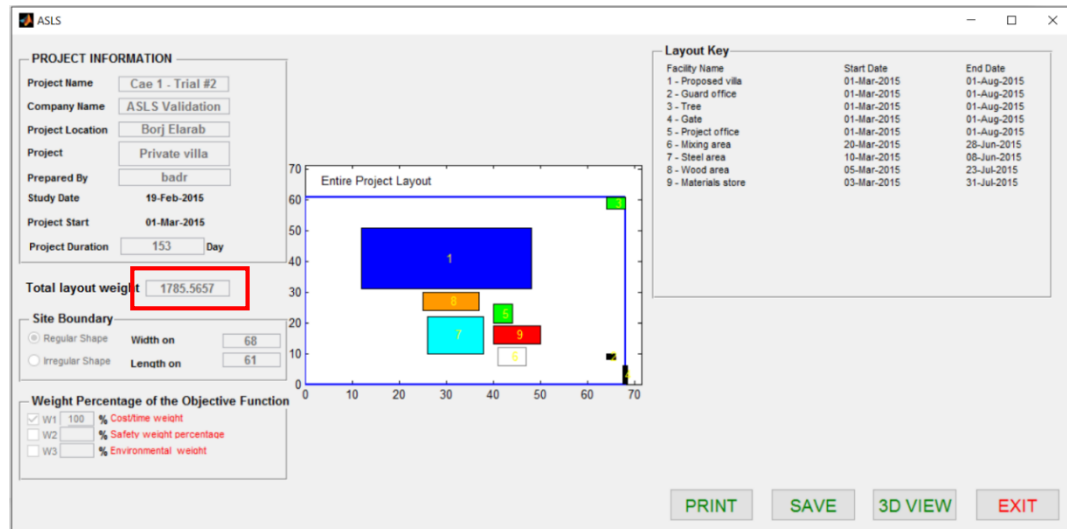


Figure (6. 17): The solution report for trial #2.

Figure (6.17.a) shows a 3D view for trial #2 generated layout.

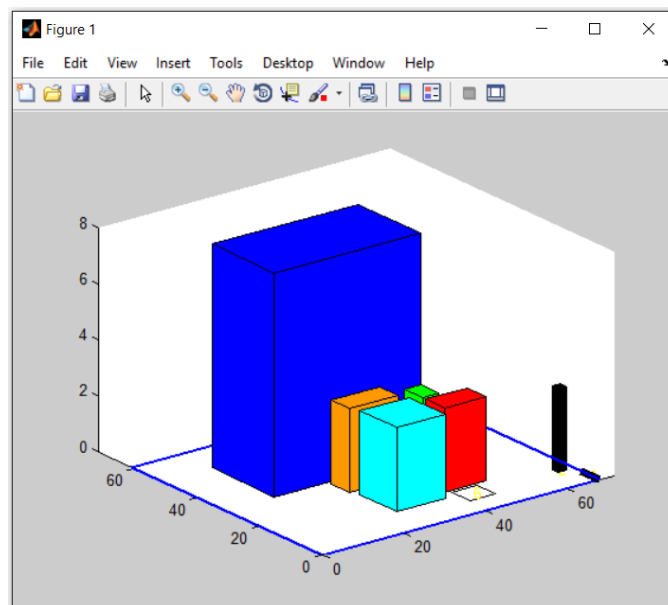
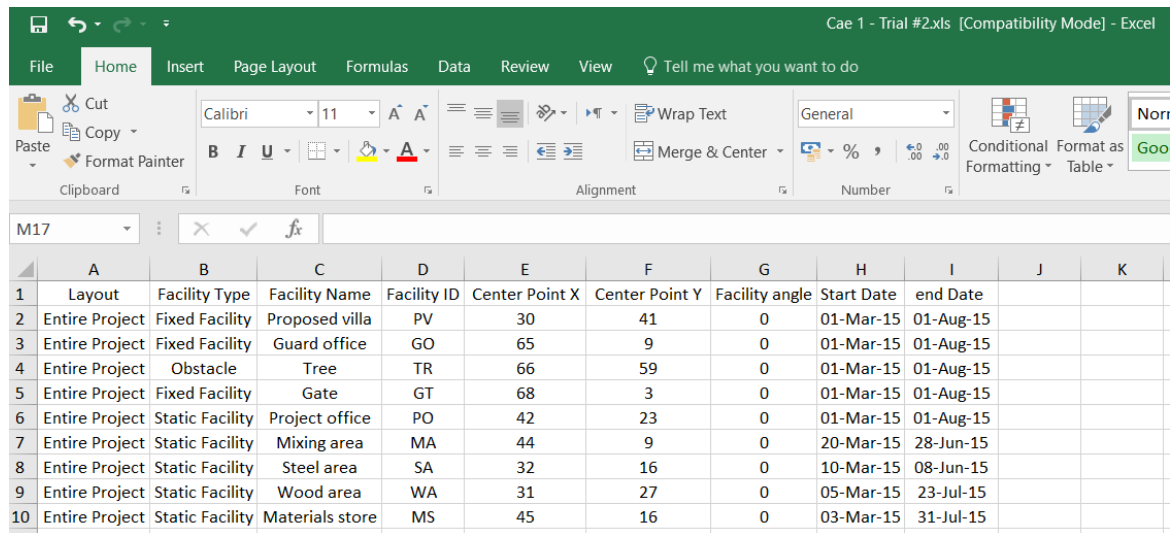


Figure (6.17. a): 3D view for trial #2 generated layout.

Figure (6.18) shows the Excel sheet generated with the solution report for trial #2.



	A	B	C	D	E	F	G	H	I	J	K
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date		
2	Entire Project	Fixed Facility	Proposed villa	PV	30	41	0	01-Mar-15	01-Aug-15		
3	Entire Project	Fixed Facility	Guard office	GO	65	9	0	01-Mar-15	01-Aug-15		
4	Entire Project	Obstacle	Tree	TR	66	59	0	01-Mar-15	01-Aug-15		
5	Entire Project	Fixed Facility	Gate	GT	68	3	0	01-Mar-15	01-Aug-15		
6	Entire Project	Static Facility	Project office	PO	42	23	0	01-Mar-15	01-Aug-15		
7	Entire Project	Static Facility	Mixing area	MA	44	9	0	20-Mar-15	28-Jun-15		
8	Entire Project	Static Facility	Steel area	SA	32	16	0	10-Mar-15	08-Jun-15		
9	Entire Project	Static Facility	Wood area	WA	31	27	0	05-Mar-15	23-Jul-15		
10	Entire Project	Static Facility	Materials store	MS	45	16	0	03-Mar-15	31-Jul-15		

Figure (6. 18): The Excel sheet generated with the solution report.

The generated solution achieves a reduction in layout weight = 686.4351, which is 27.76% less than the original layout weight developed by project's manager which means that the ASLS acts effectively in this trial.

### c. Trial #3

In this trial the ASLS will be validated for its effectiveness also by generating an optimal site layout for the examined case study during the entire project duration with the incorporation of static facilities and its orientation option in the search process. The weight of the generated layout will be compared with the weight of original site layout and supposed to have less weight in order to prove the ASLS effectiveness. The project data and the project facilities data (Table 6.4) will be inputted again same as trial #2 but this time the ASLS will allow static facilities to orient with angles options (Figure 6.19).

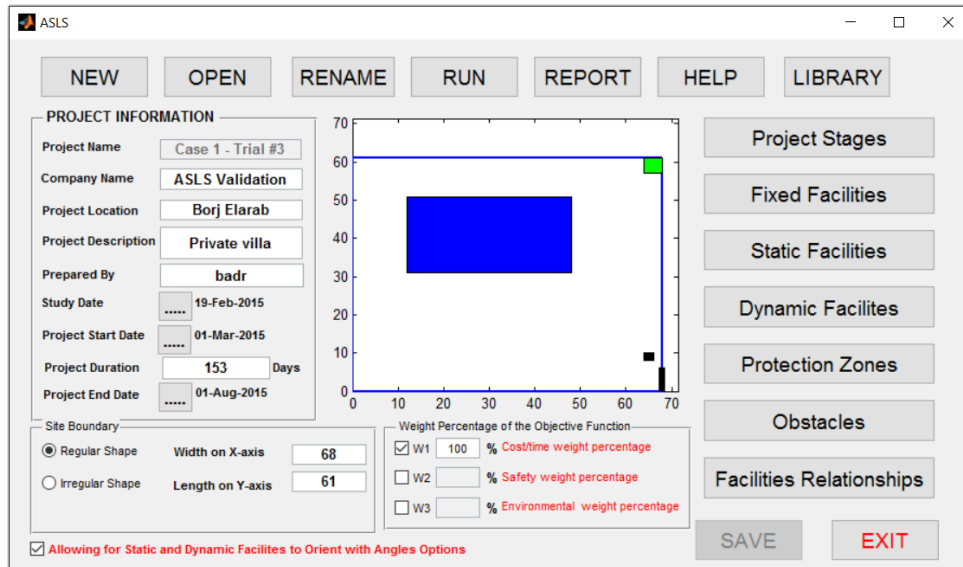


Figure (6. 19): Project data inputted to the ASLS for trial #2 with allowing for the static facilities to orient with angles options

After finishing the project data inputting, the ASLS will be used to locate an optimal space for the inputted static facilities through a GA optimization search process by pressing the RUN button. After the ASLS finishes the search process, the solution report window appears and the generated layout obtains a total layout weight = 1755.981 (Figures 6.20; 6.20.a; and 6.20.b).

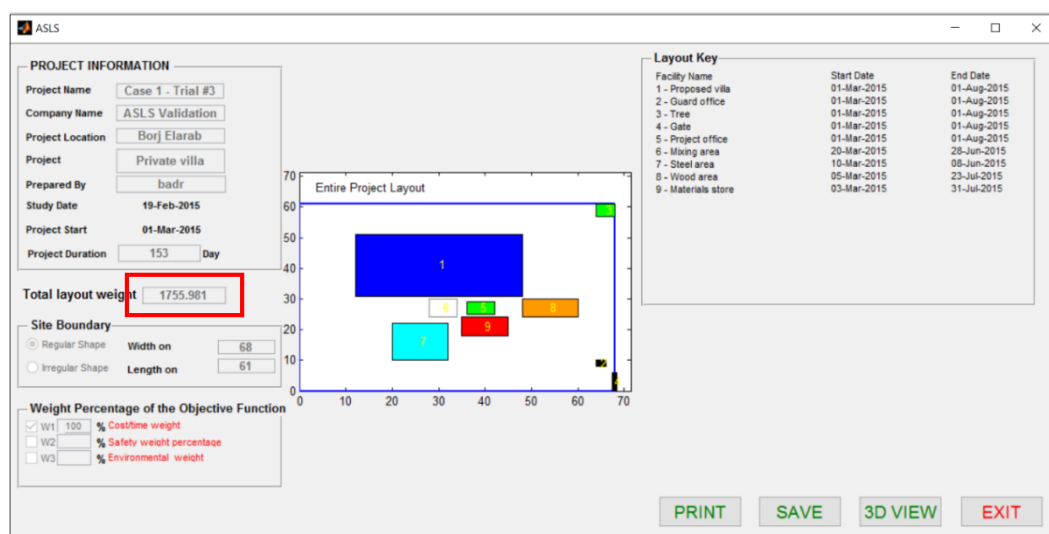


Figure (6. 20): The solution report for trial #3.

Figure (6.20.a) shows a 3D view for trial #3 generated layout.

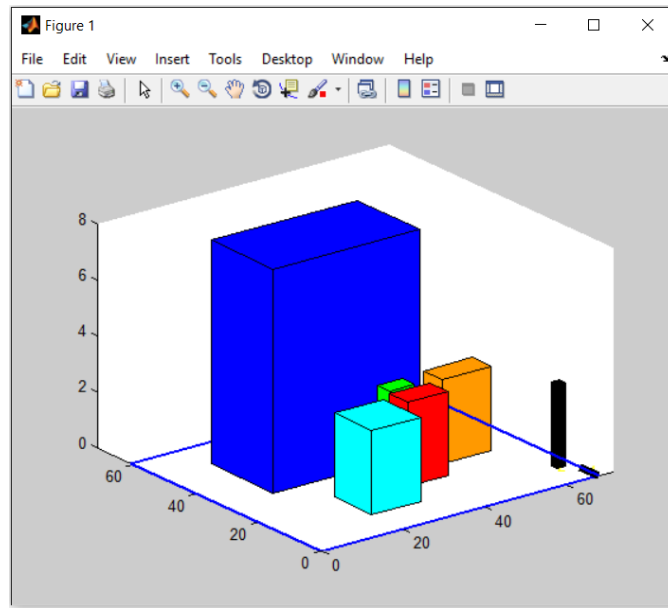


Figure (6.20. a): 3D view for trial #3 generated layout.

Figure (6.20.b) shows the Excel sheet generated with the solution report for trial #3.

Case 1 - Trial #3.xls [Compatibility Mode] - Excel											
	A	B	C	D	E	F	G	H	I	J	K
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date		
2	Entire Project	Fixed Facility	Proposed villa	PV	30	41	0	01-Mar-15	01-Aug-15		
3	Entire Project	Fixed Facility	Guard office	GO	65	9	0	01-Mar-15	01-Aug-15		
4	Entire Project	Obstacle	Tree	TR	66	59	0	01-Mar-15	01-Aug-15		
5	Entire Project	Fixed Facility	Gate	GT	68	3	0	01-Mar-15	01-Aug-15		
6	Entire Project	Static Facility	Project office	PO	39	27	270	01-Mar-15	01-Aug-15		
7	Entire Project	Static Facility	Mixing area	MA	31	27	180	20-Mar-15	28-Jun-15		
8	Entire Project	Static Facility	Steel area	SA	26	16	180	10-Mar-15	08-Jun-15		
9	Entire Project	Static Facility	Wood area	WA	54	27	0	05-Mar-15	23-Jul-15		
10	Entire Project	Static Facility	Materials store	MS	40	21	0	03-Mar-15	31-Jul-15		

Figure (6.20. b): The Excel sheet generated with the solution report.

The generated solution achieves a reduction in layout weight = 716.0198, which is 28.96% less than the original layout weight developed by project's manager which means that the ASLS acts effectively in this trial.

#### d. Discussion

Based on the simulation experiment validation scenario, the ASLS acted accurately and effectively in this case study by calculating the same layout weight as the original layout weight developed by project's manager in the first trial. In addition, the ASLS obtained 27.76% and 28.96% reduction in layout weights in the second and third trials respectively than the original layout weight developed by project's manager. It is worth noting that the ASLS obtained a larger percentage of layout weight reduction in the third trial which had allowed the use of ASLS orientation option. This result confirmed on the ASLS capabilities effectiveness. But for further confirmation of the ASLS validity for construction industry it will be subjected to another case study in the next section.

#### 6.6.2. Case Study 2

The simulation experiment second case study is used to validate the ASLS. It will be a large-scale project. The project is an educational building of area 1000 m<sup>2</sup>, while the total area of the site including the proposed building is 5761 m<sup>2</sup> as shown in figure (6.21).

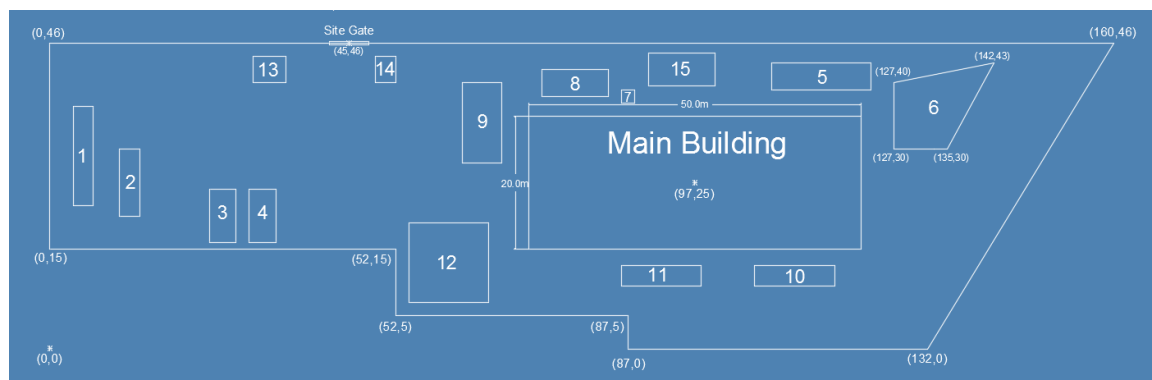


Figure (6. 21): The original site layout developed by The project's manager.

This site is located in Abu Kir, Alexandria, Egypt and includes 15 as well as the proposed building and site gate as shown in table (6.5). The project's budget= 30 million EGP. The project's start date is the 28<sup>th</sup> of March 2014 and end on the 1<sup>st</sup> of November 2014, the project duration is 214 days.



Table (6. 5): The project's facilities data.

No.	Facility Name	Facility I.D.	Facility Type	Facility Size (W*L*H) in meters	Center Point	Start Date	End Date	Duration (Days)
--	Site Gate	SG	Fixed Facility	6*0*0	45,46	28/03/2014	01/11/2014	218
--	Main Building	MB	Fixed Facility	50*20*20	97,25	28/03/2014	01/11/2014	218
1	Engineers Offices	EO	Fixed Facility	3*15*3	5,29	28/03/2014	01/11/2014	218
2	Manger Office	MO	Fixed Facility	3*10*3	12,25	28/03/2014	01/11/2014	218
3	Container for Storage	C1	Fixed Facility	4*8*3	26,20	28/03/2014	01/11/2014	218
4	Container for Storage 2	C2	Fixed Facility	4*8*3	32,20	28/03/2014	01/11/2014	218
5	Steel Storage	SS	Fixed Facility	15*4*3	116,41	01/04/2014	15/9/2014	167
6	Steel Fabrication Area	SF	Fixed Facility	**	133,36	01/04/2014	15/9/2014	167
7	Concrete Pump	CP	Fixed Facility	2*2*1	87,38	01/04/2014	15/9/2014	167
8	Ready Mix Trucks Parking Area	RM	Fixed Facility	10*4*0	79,40	01/04/2014	15/9/2014	167
9	Open Storage	OS	Fixed Facility	6*12*0	65,35	01/04/2014	01/11/2014	214
10	Scaffolding Storage	SC	Fixed Facility	12*3	112,11	01/04/2014	01/11/2014	214
11	Formwork Storage	FW	Fixed Facility	12*3*3	92,11	01/04/2014	15/9/2014	167
12	Labor Rest Area	LA	Fixed Facility	12*12*3	60,13	28/03/2014	01/11/2014	218
13	Dump Area	DA	Fixed Facility	4*5*0	33,42	05/04/2014	01/11/2014	210
14	Guard Office	GO	Fixed Facility	4*5*3	50,5,42	28/03/2014	01/11/2014	218
15	Carpentry Workshop and Wood Storage	CW	Fixed Facility	8*4*3	95,42	01/04/2014	01/10/2014	179

\*\* irregular shape with height=0 and vertices coordinates= (127,30), (135,30), (142,43) and (127,40).

Figure (6.21) has shown the site layout developed by the project's manager based on his own experience in order to minimize the overall project's cost and time. This site layout will be used in validating the ASLS, so the project's manager is assigned to

identify the cost and time closeness relationship weights between the required facilities in order to be used in the ASLS optimal site layout search process (Table 6.6).

Table (6. 6): The cost and time closeness relationship weights between the project facilities that identified by the project's manager.

Facility name/number	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Main Building
Site Gate	5	9	9	4	4	4	7	7	5	0	7	7	7	7	7	0
Main Building	9	6	9	9	9	9	9	9	9	9	9	7	7	5	7	
1	0	5	0	0	5	4	4	3	3	0	3	3	3	7		
2	0	5	0	0	5	4	4	3	0	0	0	0	0			
3	0	0	0	0	4	4	0	0	0	0	0	7				
4	0	0	0	0	4	4	0	0	0	0	0					
5	0	0	0	0	0	0	0	0	0	9						
6	0	0	5	0	0	0	0	0	0							
7	0	0	0	0	0	0	4	9								
8	0	0	0	0	0	0	4									
9	0	0	0	0	0	0										
10	0	0	0	0	5											
11	0	0	0	0												
12	0	0	0													
13	0	0														
14	0															

The ASLS will be validated through this case by three trials. The first trial is setup for validating the ASLS accuracy while the other two trials are setup for validating the ASLS effectiveness as follow:

a. Trial #1

In this trial the ASLS will be validated for its calculations accuracy not for generating an optimal site layout, by inputting the project data mentioned above and the project facilities data (Table 6.5) same as the case study data as shown in figures (6.22; 6.22.a; and 6.22.b).

The ASLS main interface displays project information on the left, a site map in the center, and facility categories on the right. The project information includes fields for Project Name, Company Name, Project Location, Project Description, Prepared By, Study Date, Project Start Date, Project Duration, and Project End Date. The site map shows a blue polygon representing the site boundary with various facilities plotted inside. The facility categories on the right include Project Stages, Fixed Facilities, Static Facilities, Dynamic Facilities, Protection Zones, Obstacles, and Facilities Relationships. A 'Weight Percentage of the Objective Function' section allows users to set weights for Cost/time, Safety, and Environmental factors. A 'Site Boundary' section provides options for Regular or Irregular shapes with vertex coordinates.

**PROJECT INFORMATION**

Project Name: Case 2 - Trial #1  
 Company Name: ASLS Validation  
 Project Location: Alex  
 Project Description: Educational building  
 Prepared By: Badr  
 Study Date: 01-Apr-2014  
 Project Start Date: 28-Mar-2014  
 Project Duration: 218 Days  
 Project End Date: 01-Nov-2014

**Site Boundary**

Regular Shape X-Vertices: 0 52 52 87 87 132 160  
 Irregular Shape Y-Vertices: 15 15 5 5 0 0 46 46  
 (Enter X, Y vertices in order)

**Weight Percentage of the Objective Function**

☒ W1 100 % Cost/time weight percentage  
☐ W2 % Safety weight percentage  
☐ W3 % Environmental weight percentage

☐ Allowing for Static and Dynamic Facilities to Orient with Angles Options

**Facility Categories:** Project Stages, Fixed Facilities, Static Facilities, Dynamic Facilities, Protection Zones, Obstacles, Facilities Relationships

**Buttons:** NEW, OPEN, RENAME, RUN, REPORT, HELP, LIBRARY, SAVE, EXIT

Figure (6. 22): Project data inputted to the ASLS for trial #1.

Figure (6.22.a) shows the site facilities after inputted in the ASLS as fixed facilities only.

The 'Fixed Facilities' dialog box provides detailed information for a specific facility. It includes fields for Facility Name, Facility ID, Start Date, Duration, Location (X, Y), Height, Orientation, Safe Distance, Color, and Facility Shape. A list of facilities is shown on the right, with 'Manager Office' selected. The dialog also includes buttons for Site Gates, Import from Library, Export to Library, SAVE, ADD, DELETE, and EXIT.

**Facility Name:** Manager Office  
**Facility ID:** MO  
**Start Date:** 28-Mar-2014  
**Duration:** 218 Day  
**Location:** X: 12, Y: 25  
 (coordinates of facility center point)  
**Height:** 3 m ☒ with roof  
**Orientation:** 0 Degrees  
**Safe Distance:** 0 m  
 (Clear distance around the facility area)  
**Color:** Black  
**Facility Shape:** Regular Shape (selected)  
 Width on X-axis: 3  
 Length on Y-axis: 10

**Facility List:** main Building, Engineers Offices, Manager Office, Countener for Storge, Countener for Storge 2, Steel Storge, Steel Fabrecation Area, Concreat pump, Ready makes trucks ba, open storge, schafolding storge, Formwork storge, Labour rest Area, Dump Area

**Buttons:** Site Gates, Import from Library, Export to Library, SAVE, ADD, DELETE, EXIT

Figure (6.22. a): Fixed facilities data.

Figure (6.22.b): shows the relationship weights between the project facilities after inputted in the ASLS.

Facilities Relationships

Cost / time closeness relationships    Safety concern closeness relationships    Environmental concern closeness relationships

EF    MF    PF    IF    TP    UP

Average relationships

- Please fill the relations between facilities with average weights that express the six governing factors or fill each governing factors separately.  
 - Please fill the relations between facilities with a 9-point scale.  
 - 9 indicate a significant relationship between two facilities and they should be assigned as close as possible.  
 - 0 indicates that facilities should be assigned far away from each other.

	Site Gate	Carbentry workshop & Wood storage	Gard Office	Dump Area	Labour rest Area	Formwork storage	schaftolding storage	open storage
main Building	0	9	6	9	9	9	9	9
Engineers Offices	7	9	5	0	0	5	4	4
Manager Office	7	0	5	0	0	5	4	4
Countener for Storage	7	0	0	0	0	4	4	0
Countener for Storage 2	7	0	0	0	0	4	4	0
Steel Storage	7	0	0	0	0	0	0	0
Steel Fabrication Area	0	0	0	5	0	0	0	0
Concreat pump	5	0	0	0	0	0	0	4
Ready makes trucks barking Area	7	0	0	0	0	0	0	4
open storage	7	0	0	0	0	0	0	0
schaftolding storage	4	0	0	0	0	5	0	0
Formwork storage	4	0	0	0	0	0	0	0
Labour rest Area	4	0	0	0	0	0	0	0
Dump Area	9	0	0	0	0	0	0	0
Gard Office	9	0	0	0	0	0	0	0
Carbentry workshop & Wood storage	5	0	0	0	0	0	0	0

<    >

Clear    SAVE    EXIT

Figure (6.22. b): The relationship weights between the project facilities.

After finishing the project data inputting, the ASLS will be used to calculate the overall layout weight of the original facilities locations by pressing the REPORT button. The solution report windows will appear (Figures 6.23; 6.23.a; and 6.24), the calculated layout weight by the ASLS should be equal to the manually calculated – by Excel sheet – layout weight for the original layout (Figure 6.25) in order to prove the calculations accuracy of the ASLS. In this trial the ASLS is validated for the calculations accuracy only without any optimization search process for new facilities location as they all inputted as fixed facilities only.

ASLS

PROJECT INFORMATION

Project Name: Case 2 - Trial #1  
 Company Name: ASLS Validation  
 Project Location: Alex  
 Project: Educational building  
 Prepared By: Badr  
 Study Date: 01-Apr-2014  
 Project Start: 28-Mar-2014  
 Project Duration: 218 Day

Total layout weight: 12783.3167

Site Boundary  
☐ Regular Shape  
☒ Irregular Shape

Weight Percentage of the Objective Function  
☒ W1: 100 % Cost/Time weight  
☐ W2: % Safety weight percentage  
☐ W3: % Environmental weight

Layout Key

Facility Name	Start Date	End Date
1 - main Building	28-Mar-2014	01-Nov-2014
2 - Engineers Offices	28-Mar-2014	01-Nov-2014
3 - Manager Office	28-Mar-2014	01-Nov-2014
4 - Countener for Storage	28-Mar-2014	01-Nov-2014
5 - Countener for Storage 2	28-Mar-2014	01-Nov-2014
6 - Steel Storage	01-Apr-2014	15-Sep-2014
7 - Steel Fabrication Area	01-Apr-2014	15-Sep-2014
8 - Concreat pump	01-Apr-2014	15-Sep-2014
9 - Ready makes trucks barking Area	01-Apr-2014	15-Sep-2014
10 - open storage	01-Apr-2014	15-Sep-2014
11 - schaftolding storage	01-Apr-2014	15-Sep-2014
12 - Formwork storage	28-Mar-2014	01-Nov-2014
13 - Labour rest Area	05-Apr-2014	01-Nov-2014
14 - Dump Area	28-Mar-2014	01-Nov-2014
15 - Gard Office	01-Apr-2014	27-Sep-2014

Entire Project Layout

PRINT    SAVE    3D VIEW    EXIT

Figure (6. 23): The solution report for trial #1.

The calculated layout weight by the ASLS for the original facilities locations = 12783.3167.

Figure (6.23.a) shows a 3D view for the original layout developed by the ASLS.

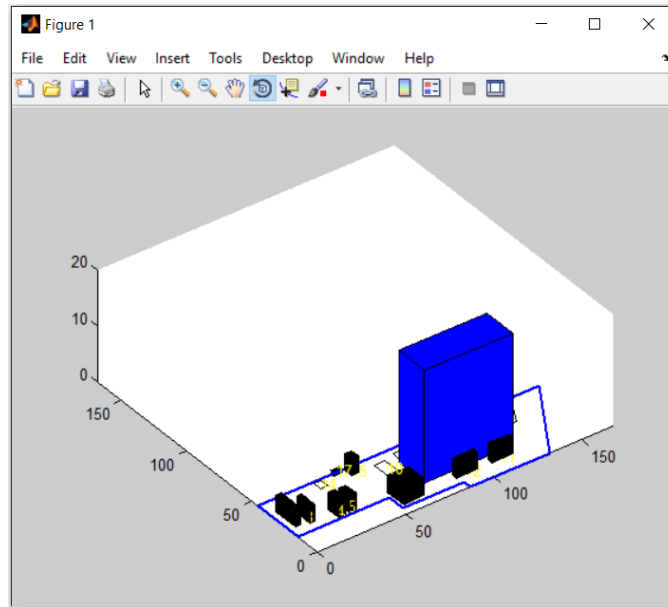


Figure (6.23. a): 3D view for the original layout developed by the ASLS.

Figure (6.24) shows the Excel sheet generated with the solution report that contains main data for the site facilities.

Case 2 - Trial #1.xls [Compatibility Mode] - Excel									
File Home Insert Page Layout Formulas Data Review View Tell me what you want to do									
Clipboard Font Alignment Number Styles									
	A	B	C	D	E	F	G	H	I
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date
2	Entire Project	Fixed Facility	Main Building	MB	97	25	0	28-Mar-14	01-Nov-14
3	Entire Project	Fixed Facility	Engineers Offices	EO	5	29	0	28-Mar-14	01-Nov-14
4	Entire Project	Fixed Facility	Manager Office	MO	12	25	0	28-Mar-14	01-Nov-14
5	Entire Project	Fixed Facility	Countener for Storge	C1	26	20	0	28-Mar-14	01-Nov-14
6	Entire Project	Fixed Facility	Counterter for Storge 2	C2	32	20	0	28-Mar-14	01-Nov-14
7	Entire Project	Fixed Facility	Steel Storge	SS	116	41	0	01-Apr-14	15-Sep-14
8	Entire Project	Fixed Facility	Steel Fabrecation Area	SF	133	36	0	01-Apr-14	15-Sep-14
9	Entire Project	Fixed Facility	Concreat pump	CP	87	38	0	01-Apr-14	15-Sep-14
10	Entire Project	Fixed Facility	Ready makes trucks barking Area	RM	79	40	0	01-Apr-14	15-Sep-14
11	Entire Project	Fixed Facility	open storge	OS	65	34	0	01-Apr-14	01-Nov-14
12	Entire Project	Fixed Facility	schaftolding storge	SC	112	11	0	01-Apr-14	01-Nov-14
13	Entire Project	Fixed Facility	Formwork storge	FW	92	11	0	01-Apr-14	15-Sep-14
14	Entire Project	Fixed Facility	Labour rest Area	LA	60	13	0	28-Mar-14	01-Nov-14
15	Entire Project	Fixed Facility	Dump Area	DA	33	42	0	05-Apr-14	01-Nov-14
16	Entire Project	Fixed Facility	Gard Office	GO	50.5	42	0	28-Mar-14	01-Nov-14
17	Entire Project	Fixed Facility	Carbentary workshop & Wood storge	CW	95	42	0	01-Apr-14	27-Sep-14
18	Entire Project	Fixed Facility	Site Gate	SG	45	46	0	28-Mar-14	01-Nov-14

Figure (6. 24): The Excel sheet generated with the solution report.

[illegible]

The manually calculated layout weight by the Excel sheet for the original site layout = 12783.3167.

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Due to the changing in the facilities type's in trials two and three, the facilities numbering will change in the ASLS solution report according to the method that the ASLS involved them in the search process (fixed facilities, obstacles, site gates, protection zones, static facilities then dynamic facilities).

b. Trial #2

In this trial the ASLS will be validated for its effectiveness, by generating an optimal site layout for the examined case study during the entire project duration with the incorporation of static facilities in the search process. The weight of the generated layout will be compared with the weight of original site layout and supposed to have less weight in order to prove the ASLS effectiveness. The project data and the project facilities data (Table 6.7) will be inputted again, but this time the Engineers Offices, Manger Office, Container for Storage, Container for Storage 2, Steel Storage, Steel Fabrication Area, Concrete Pump, Ready Mix Trucks Parking Area, Open Storage, Scaffolding Storage, Formwork Storage, Labor Rest Area, Dump Area and Carpentry Workshop and wood storage inputted as static facilities (Figures 6.26; and 6.26. a).

Table (6. 7): The project's facilities data for Trial #2.

No.	Facility Name	Facility I.D.	Facility Type	Facility Size (W*L*H) in meters	Center Point	Start Date	End Date	Duration (Days)
--	Site Gate	SG	Fixed Facility	6*0*0	45,46	28/03/2014	01/11/2014	218
--	Main Building	MB	Fixed Facility	50*20*20	97,25	28/03/2014	01/11/2014	218
1	Engineers Offices	EO	Static Facility	3*15*3	--	28/03/2014	01/11/2014	218
2	Manger Office	MO	Static Facility	3*10*3	--	28/03/2014	01/11/2014	218
3	Container for Storage	C1	Static Facility	4*8*3	--	28/03/2014	01/11/2014	218
4	Container for Storage 2	C2	Static Facility	4*8*3	--	28/03/2014	01/11/2014	218
5	Steel Storage	SS	Static Facility	15*4*3	--	01/04/2014	15/9/2014	167
6	Steel Fabrication Area	SF	Static Facility	**	--	01/04/2014	15/9/2014	167
7	Concrete Pump	CP	Static Facility	2*2*1	--	01/04/2014	15/9/2014	167
8	Ready Mix Trucks Parking Area	RM	Static Facility	10*4*0	--	01/04/2014	15/9/2014	167
9	Open Storage	OS	Static Facility	6*12*0	--	01/04/2014	01/11/2014	214
10	Scaffolding Storage	SC	Static Facility	12*3	--	01/04/2014	01/11/2014	214
11	Formwork Storage	FW	Static Facility	12*3*3	--	01/04/2014	15/9/2014	167
12	Labor Rest Area	LA	Static Facility	12*12*3	--	28/03/2014	01/11/2014	218
13	Dump Area	DA	Static Facility	4*5*0	--	05/04/2014	01/11/2014	210
14	Guard Office	GO	Fixed Facility	4*5*3	50.5,42	28/03/2014	01/11/2014	218
15	Carpentry Workshop and Wood Storage	CW	Static Facility	8*4*3	--	01/04/2014	01/10/2014	179

\*\* irregular shape with vertices coordinates= (127,30), (135,30), (142,43) and (127,40).



Figure (6.26): shows the project data for trial # 2.

The ASLS Project Information window displays the following data for trial #2:

- Project Name:** Case 2 - Trial #2
- Company Name:** ASLS Validation
- Project Location:** Alx
- Project Description:** Educational building
- Prepared By:** Badr
- Study Date:** 01-Apr-2014
- Project Start Date:** 28-Mar-2014
- Project Duration:** 218 Days
- Project End Date:** 01-Nov-2014

**Site Boundary:**

- ☐ Regular Shape X-Vertices: 0 52 52 87 87 132 160
- ☒ Irregular Shape Y-Vertices: 15 15 5 5 0 0 46 46

(Enter X , Y vertices in order)

**Weight Percentage of the Objective Function:**

- ☒ W1 100 % Cost/time weight percentage
- ☐ W2 % Safety weight percentage
- ☐ W3 % Environmental weight percentage

☐ Allowing for Static and Dynamic Facilities to Orient with Angles Options

**Buttons:** NEW, OPEN, RENAME, RUN, REPORT, HELP, LIBRARY, Project Stages, Fixed Facilities, Static Facilities, Dynamic Facilities, Protection Zones, Obstacles, Facilities Relationships, SAVE, EXIT.

Figure (6. 26): Project data inputted to the ASLS for trial #2.

Figure (6.26.a): shows the site facilities which inputted as static facilities for trial # 2.

The Static Facilities window displays the following data for the Engineers Offices facility:

- Facility Name:** Engineers Offices
- Facility ID:** EO
- Arrival Date:** 28-Mar-2014
- Duration:** 218 Day
- Height:** 3 m
- Safe Distance:** 0 m
- Color:** Cyan
- Facility Shape:**
  - ☒ Regular Shape Width on X-axis: 3
  - ☐ Irregular Shape Length on Y-axis: 15

**Buttons:** Import from Library, Export to Library, SAVE, ADD, DELETE, EXIT.

Figure (6.26. a): The static facilities data.

After finishing the project data inputting, the ASLS will be used to locate an optimal space for the inputted static facilities through a GA optimization search process by pressing the RUN button. After the ASLS finishes the search process, the solution report window appears and the generated layout obtains a total layout weight = 12160.5902 (Figures 6.27; 6.27.a; and 6.28).

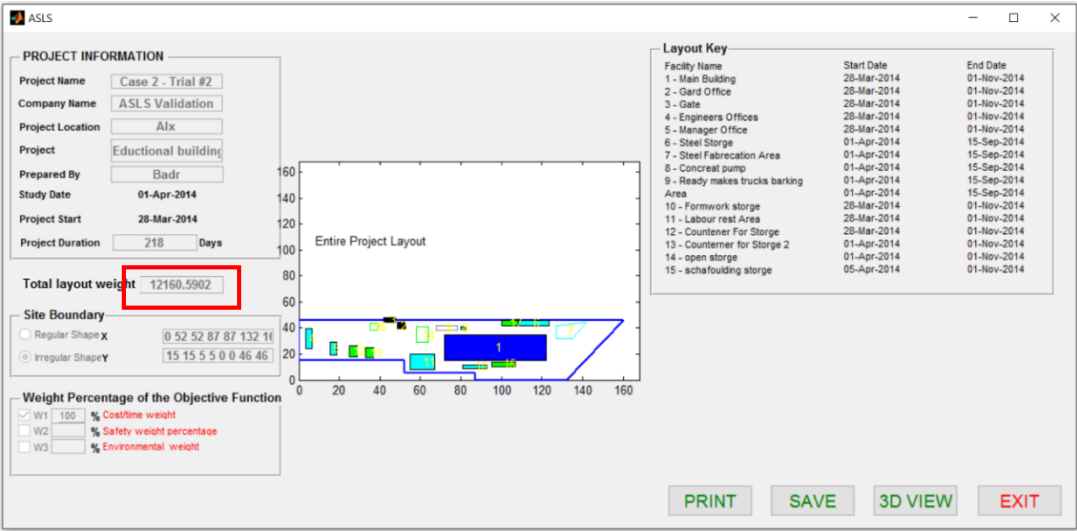


Figure (6. 27): The solution report for trial #2.

Figure (6.27.a) shows a 3D view for trial #2 generated layout.

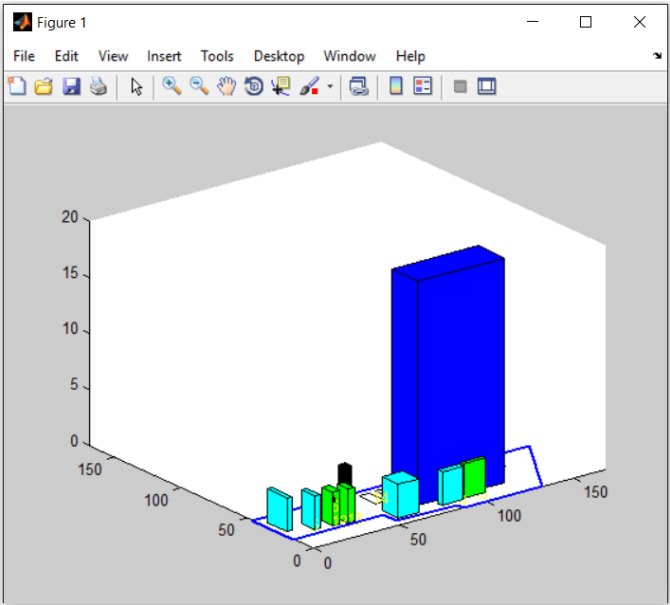


Figure (6. 27.a): 3D view for trial #2 generated layout.

Figure (6.28) shows the Excel sheet generated with the solution report for trial #2.

	A	B	C	D	E	F	G	H	I	J
1	Layout	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date	
2	Entire Project	Fixed Facility	Main Building	MB	97	25	0	28-Mar-14	01-Nov-14	
3	Entire Project	Fixed Facility	Gard Office	GO	50.5	42	0	28-Mar-14	01-Nov-14	
4	Entire Project	Fixed Facility	Gate	GT	45	46	0	28-Mar-14	01-Nov-14	
5	Entire Project	Static Facility	Engineers Offices	EO	5	32	0	28-Mar-14	01-Nov-14	
6	Entire Project	Static Facility	Manager Office	MO	17	24	0	28-Mar-14	01-Nov-14	
7	Entire Project	Static Facility	Steel Storage	SS	116	44	0	01-Apr-14	15-Sep-14	
8	Entire Project	Static Facility	Steel Fabrecation Area	SF	133	38	0	01-Apr-14	15-Sep-14	
9	Entire Project	Static Facility	Concreat pump	CP	81	40	0	01-Apr-14	15-Sep-14	
10	Entire Project	Static Facility	Ready makes trucks barking Area	RM	73	40	0	01-Apr-14	15-Sep-14	
11	Entire Project	Static Facility	Formwork storge	FW	87	10	0	01-Apr-14	15-Sep-14	
12	Entire Project	Static Facility	Labour rest Area	LA	61	14	0	28-Mar-14	01-Nov-14	
13	Entire Project	Static Facility	Countener For Storge	C1	27	22	0	28-Mar-14	01-Nov-14	
14	Entire Project	Static Facility	Countener for Storge 2	C2	35	21	0	28-Mar-14	01-Nov-14	
15	Entire Project	Static Facility	open storge	OS	61	35	0	01-Apr-14	01-Nov-14	
16	Entire Project	Static Facility	schafoulding storge	SC	101	12	0	01-Apr-14	01-Nov-14	
17	Entire Project	Static Facility	Dump Area	DA	37	41	0	05-Apr-14	01-Nov-14	
18	Entire Project	Static Facility	Carpentry workshop & Wood Storge	CW	104	44	0	01-Apr-14	27-Sep-14	

Figure (6. 28): The Excel sheet generated with the solution report.

The generated solution achieves a reduction in layout weight = 662.7265, which is 4.83% less than the original layout weight developed by project's manager which means that the ASLS acts effectively in this trial.

### c. Trial #3

In this trial the ASLS will be validated for its effectiveness also by generating an optimal site layout for the examined case study with the incorporation of static facilities, dynamic facilities and project stages in the search process. The weight of the generated layout will be compared with the weight of original site layout and supposed to have less weight in order to prove the ASLS effectiveness. The project data and the project facilities data (Table 6.8) will be inputted again as trial #2 but this time the Engineers Offices, Manger Office, Steel Storage, Steel Fabrication Area, Concrete Pump, Ready Mix Trucks Parking Area, Formwork Storage and Labor Rest Area will be static facilities. While the Container for Storage, Container for Storage 2, Open Storage, Scaffolding Storage, Dump Area, Carpentry Workshop and wood storage will

be dynamic facilities (Figures 6.29; and 6.29.a). The weights need to relocate the dynamic facilities ( $F_i$ ) and ( $R_i$ ) shown in table (6.9).

Table (6. 8): The project's facilities data for Trial #3.

No.	Facility Name	Facility I.D.	Facility Type	Facility Size (W*L*H) in meters	Center Point	Start Date	End Date	Duration (Days)
--	Site Gate	SG	Fixed Facility	6*0*0	45,46	28/03/2014	01/11/2014	218
--	Main Building	MB	Fixed Facility	50*20*20	97,25	28/03/2014	01/11/2014	218
1	Engineers Offices	EO	Static Facility	3*15*3	--	28/03/2014	01/11/2014	218
2	Manger Office	MO	Static Facility	3*10*3	--	28/03/2014	01/11/2014	218
3	Container for Storage	C1	Dynamic Facility	4*8*3	--	28/03/2014	01/11/2014	218
4	Container for Storage 2	C2	Dynamic Facility	4*8*3	--	28/03/2014	01/11/2014	218
5	Steel Storage	SS	Static Facility	15*4*3	--	01/04/2014	15/9/2014	167
6	Steel Fabrication Area	SF	Static Facility	**	--	01/04/2014	15/9/2014	167
7	Concrete Pump	CP	Static Facility	2*2*1	--	01/04/2014	15/9/2014	167
8	Ready Mix Trucks Parking Area	RM	Static Facility	10*4*0	--	01/04/2014	15/9/2014	167
9	Open Storage	OS	Dynamic Facility	6*12*0	--	01/04/2014	01/11/2014	214
10	Scaffolding Storage	SC	Dynamic Facility	12*3	--	01/04/2014	01/11/2014	214
11	Formwork Storage	FW	Static Facility	12*3*3	--	01/04/2014	15/9/2014	167
12	Labor Rest Area	LA	Static Facility	12*12*3	--	28/03/2014	01/11/2014	218
13	Dump Area	DA	Dynamic Facility	4*5*0	--	05/04/2014	01/11/2014	210
14	Guard Office	GO	Fixed Facility	4*5*3	50.5,42	28/03/2014	01/11/2014	218
15	Carpentry Workshop and Wood Storage	CW	Static Facility	8*4*3	--	01/04/2014	01/10/2014	179

\*\* irregular shape with height=0 and vertices coordinates= (127,30), (135,30), (142,43) and (127,40).

Table (6.9) shows the weights needed to relocate the dynamic facilities ( $F_i$ ) and ( $R_i$ ).

Table (6. 9): The relocation cost for dynamic facilities.

No.	Facility Name	Facility I.D.	Facility Type	( $F_i$ )	( $R_i$ )
3	Container for Storage	C1	Dynamic Facility	0	2
4	Container for Storage	C2	Dynamic Facility	0	2
9	Open Storage	OS	Dynamic Facility	0	0
13	Dump Area	DA	Dynamic Facility	0	0

Figure (6.29): shows the project data for trial # 3.

ASLS

NEW OPEN RENAME RUN REPORT HELP LIBRARY

**PROJECT INFORMATION**

Project Name: Case 2 - Trial #3

Company Name: ASLS Validation

Project Location: Alx

Project Description: Educational building

Prepared By: Badr

Study Date: 01-Apr-2014

Project Start Date: 28-Mar-2014

Project Duration: 218 Days

Project End Date: 01-Nov-2014

Site Boundary

☐ Regular Shape X-Vertices: 0 52 52 87 87 132 160

☒ Irregular Shape Y-Vertices: 15 15 5 5 0 0 46 46

( Enter X , Y vertices in order )

☐ Allowing for Static and Dynamic Facilities to Orient with Angles Options

Weight Percentage of the Objective Function

☒ W1 100 % Cost/time weight percentage

☐ W2 % Safety weight percentage

☐ W3 % Environmental weight percentage

Project Stages

Fixed Facilities

Static Facilities

Dynamic Facilities

Protection Zones

Obstacles

Facilities Relationships

SAVE EXIT

Figure (6. 29): Project data inputted to the ASLS for trial #3.

Figure (6.29.a): shows the site facilities which inputted as dynamic facilities for trial # 3.

Figure (6.29. a): The dynamic facilities data.

The project duration will be divided into two stages. The two stages are divided by the project's manager based on the facilities start and end dates. Stage 1 start date is the 28<sup>th</sup> of March 2014 and end on the 15<sup>th</sup> of September 2014, the stage duration is 171 days. Stage 2 start date is the 16<sup>th</sup> of September 2014 and end on the 1<sup>st</sup> of November 2014, the stage duration is 47 days (Figure 6.30).

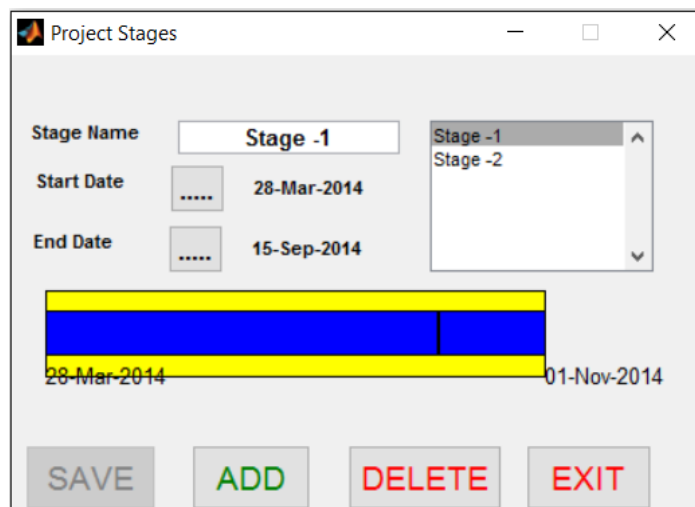


Figure (6. 30): The project stages.

After finishing the project data inputting, the ASLS will be used to locate an optimal space for the inputted static and dynamic facilities through a GA optimization search process by pressing the RUN button. After the ASLS finishes the search process, the solution report window appears and the generated layout obtains a total layout weight = 11863.3607 (Figures 6.31; 6.31.a; 6.31.b; and 6.32). Due to the incorporation of project stages in the search process for this trial, the selected solution by ASLS is the lowest layout weight. It is the stages layout and not the entire project layout.

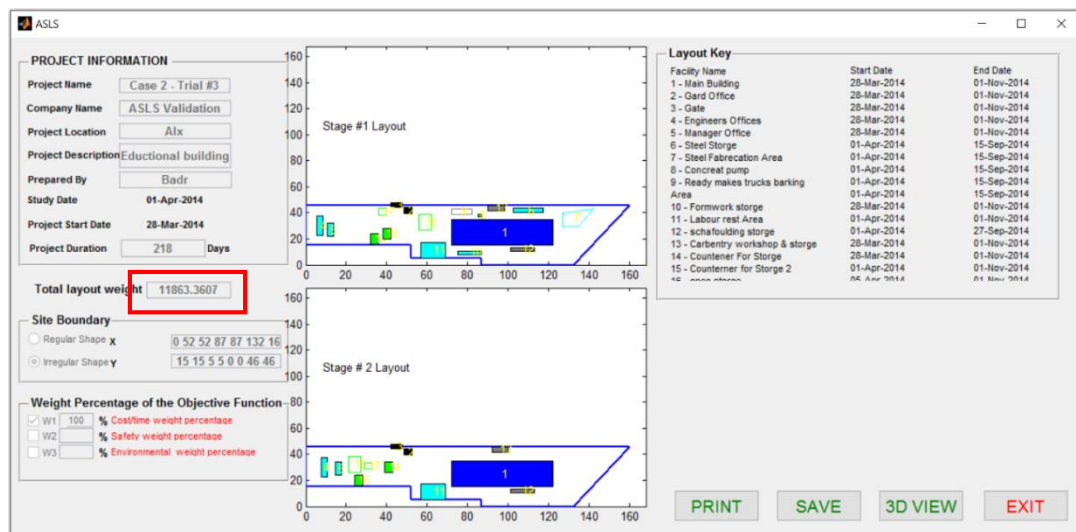


Figure (6. 31): The solution report for trial #3.

Figure (6.31.a) shows a 3D view for trial #3stage 1 generated layout.

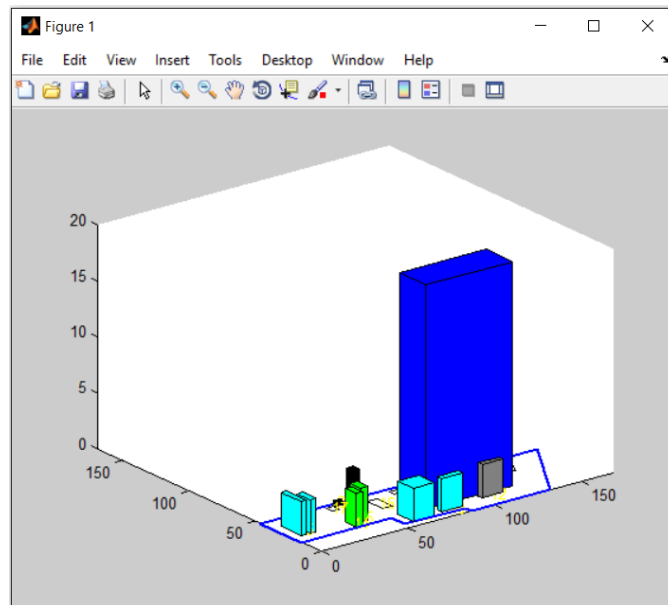


Figure (6.31. a): 3D view for trial #3 stage 1 generated layout.

Figure (6.31.b) shows a 3D view for trial #3stage 2 generated layout.

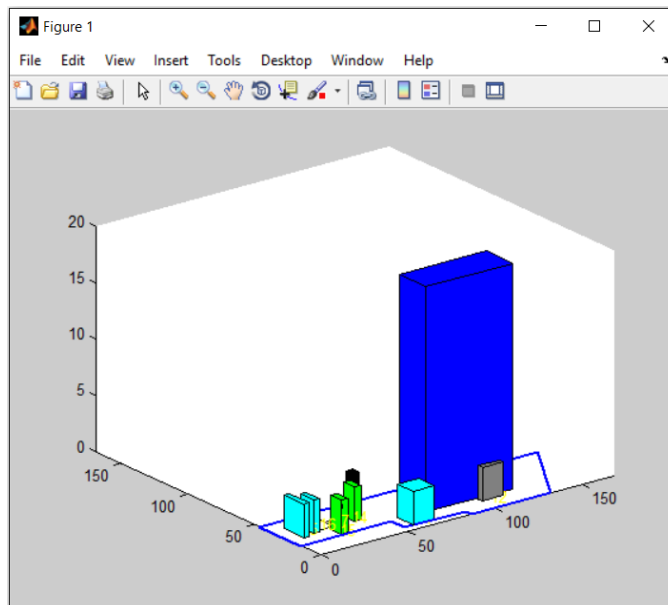


Figure (6.31. b): 3D view for trial #3stage 2 generated layout.



Figure (6.32) shows the Excel sheet generated with the solution report for trial #3.

	A	B	C	D	E	F	G	H	I	J
	Stage	Facility Type	Facility Name	Facility ID	Center Point X	Center Point Y	Facility angle	Start Date	end Date	
1	Stage -1	Fixed Facility	Main Building	MB	97	25	0	28-Mar-14	01-Nov-14	
2	Stage -1	Fixed Facility	Gard Office	GO	50.5	42	0	28-Mar-14	01-Nov-14	
3	Stage -1	Static Facility	Gate	GT	45	46	0	28-Mar-14	01-Nov-14	
4	Stage -1	Static Facility	Engineers Offices	EO	7	30	0	28-Mar-14	01-Nov-14	
5	Stage -1	Static Facility	Manager Office	MO	12	27	0	28-Mar-14	01-Nov-14	
6	Stage -1	Static Facility	Steel Storage	SS	110	42	0	01 Apr 14	15 Sep 14	
7	Stage -1	Static Facility	Steel Fabrication Area	SF	133	36	0	01-Apr-14	15-Sep-14	
8	Stage -1	Static Facility	Concrete pump	CP	86	38	0	01-Apr-14	15-Sep-14	
9	Stage -1	Static Facility	ready makes trucks parking Area	RM	77	41	0	01 Apr 14	15 Sep 14	
10	Stage -1	Static Facility	formwork storage	FW	81	9	0	01-Apr-14	15-Sep-14	
11	Stage -1	Static Facility	Labour rest Area	LA	63	11	0	28-Mar-14	01-Nov-14	
12	Stage -1	Static Facility	scaffolding storage	SC	107	12	0	01 Apr 14	01 Nov 14	
13	Stage -1	Static Facility	entry Workshop and Wood Storage	LW	94	44	0	01-Apr-14	27-Sep-14	
14	Stage -1	Dynamic Facility	Countener For Storage	C1	34	20	0	28-Mar-14	01-Nov-14	
15	Stage -1	Dynamic Facility	Countener for Storage 2	C2	40	24	0	28-Mar-14	01-Nov-14	
16	Stage -1	Dynamic Facility	open storage	OS	59	33	0	01-Apr-14	01-Nov-14	
17	Stage -1	Dynamic Facility	Dump Area	DA	38	41	0	05-Apr-14	01-Nov-14	
18	Stage -2	Fixed Facility	Main Building	MB	97	25	0	28-Mar-14	01-Nov-14	
19	Stage -2	Fixed Facility	Gard Office	GO	50.5	42	0	28-Mar-14	01-Nov-14	
20	Stage -2	Static Facility	Gate	GT	45	46	0	28-Mar-14	01-Nov-14	
21	Stage -2	Static Facility	Engineers Offices	EO	9	30	0	28-Mar-14	01-Nov-14	
22	Stage -2	Static Facility	Manager Office	MO	16	29	0	28-Mar-14	01-Nov-14	
23	Stage -2	Static Facility	Labour rest Area	LA	63	11	0	28-Mar-14	01-Nov-14	
24	Stage -2	Static Facility	scaffolding storage	SC	107	12	0	01-Apr-14	01-Nov-14	
25	Stage -2	Static Facility	entry Workshop and Wood Storage	CW	96	44	0	01-Apr-14	27-Sep-14	
26	Stage -2	Dynamic Facility	Countener For Storage	C1	41	30	0	28-Mar-14	01-Nov-14	
27	Stage -2	Dynamic Facility	Countener for Storage 2	C2	26	20	0	28-Mar-14	01-Nov-14	
28	Stage -2	Dynamic Facility	open storage	OS	24	32	0	01-Apr-14	01-Nov-14	
29	Stage -2	Dynamic Facility	Dump Area	DA	31	31	0	05-Apr-14	01-Nov-14	
30	Stage -2	Dynamic Facility								

Figure (6. 32): The Excel sheet generated with the solution report.

The generated solution achieves a reduction in layout weight = 919.95, which is 7.196% less than the original layout weight developed by project's manager which means that the ASLS acts effectively in this trial.

#### d. Discussion

Based on the simulation experiment validation scenario, the ASLS acted accurately and effectively in this case study by calculating the same layout weight as the original layout weight developed by project's manager in the first trial. In addition, the ASLS obtained 4.83% and 7.196% reduction in layout weights in the second and third trials respectively than the original layout weight developed by project's manager. It is also worth noting that the ASLS obtained a larger percentage of layout weight reduction in the third trial which had incorporated the dynamic facilities and project stages in the search process. This result confirmed on the ASLS search process capabilities effectiveness. Furthermore, the selected solution by ASLS in the third trial was the

lowest layout weight. It was the stages layout not the entire project layout. The selection of the stages layout proved the success of the dynamic search process introduced in chapter 5.

This section illustrated the details of the ASLS validation process through simulation experiment on two construction projects based in Egypt as two case studies. However, the objective of this validation process was to demonstrate the capability of the ASLS in generating optimal site layout that reflected the dynamic nature of construction sites based on the facilities actual duration to examine its accuracy and effectiveness. The ASLS was validated through three trials for each case study. The first trial in both case studies was setup for validating the ASLS accuracy while the other trials in both case studies were setup for validating the ASLS effectiveness. The weights of solutions which were calculated by the ASLS for the first trials in both case studies were quite similar to the manual calculations for the weights of the original layout developed by both project's managers. These results proved the ASLS accuracy in weight calculation. The generated solutions by the ASLS for the rest of trials in both case studies achieved a reduction in layouts weight's than the original layout weight developed by both project's managers. It was interesting to see the generated solutions by the ASLS for the third trial of both case studies achieved a larger percentage of layout weight reduction than the generated solutions for the second trial. These result confirmed on the ASLS capabilities effectiveness. Furthermore, the selected solution by ASLS in the third trial of second case study was the lowest layout weight. It was the stages layout not the entire project layout. This selection proved the success of the dynamic search process introduced in chapter 5. These results proved the ASLS effectiveness in developing optimal site layouts for construction projects. These results were achieved on the first objective function ( $f_1$ ) only that minimizing the total

handling cost and time of interaction flows between the site facilities as mentioned before in this section. The ASLS also enabled a 3D view for the generated layouts. Therefore, the next section will demonstrate the ASLS evaluation process.

## **6.7. THE ASLS EVALUATION**

After developing and validating an artifact, this artifact must subject to an evaluation process through some empirical methods “to determine how well an artifact works” (Hevner et al., 2004). However, the choice of evaluation method can vary depend on the designed artifact and the selected evaluation metrics. According to Hevner et al. (2004), IT artifacts can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability and other relevant quality attributes. For the context of this research, the ASLS has been evaluated for its completeness, performance, usability, functionality and user acceptance. Evaluating the ASLS completeness and performance will be done through functional (black-box) and structural (white-box) tests. While evaluating the ASLS usability, functionality and user acceptability will be done through the controlled experiment in terms of user trial method as mentioned before in section 4.5.

### **6.7.1. The Functional and Structural Tests**

Evaluating the ASLS completeness and performance is done through testing strategy in terms of functional (black-box) and structural (white-box) tests as mentioned before in section 4.5. The Functional (Black Box) tests are done by Performing functional test to discover failures and identify defects. While the structural (White Box) tests are done by performing coverage testing of some metric (e.g., interfaces and commands paths) in the ASLS implementation as mentioned before in section 4.7. Testing data collection is done using observations method. Observations will be used

to check, verify and evaluate the performance and completeness of the proposed automated system through the previously mentioned tests as mentioned before in section 4.6.

The testing process will be executed in two phases as mentioned before in section 4.7.

In phase one a structural (white-box) test is executed based on a small artificial case to discover any errors in logic or structure of the ASLS code then fix them. In fact, some errors occurred in the commands paths during the test as shown in figure (6.33).

Therefore, a code debugging executed by the MATLAB debugging tool to find and fix these errors. These errors were fixed by modifying the ASLS code then the test was repeated to confirm the errors modification and fixing processes.

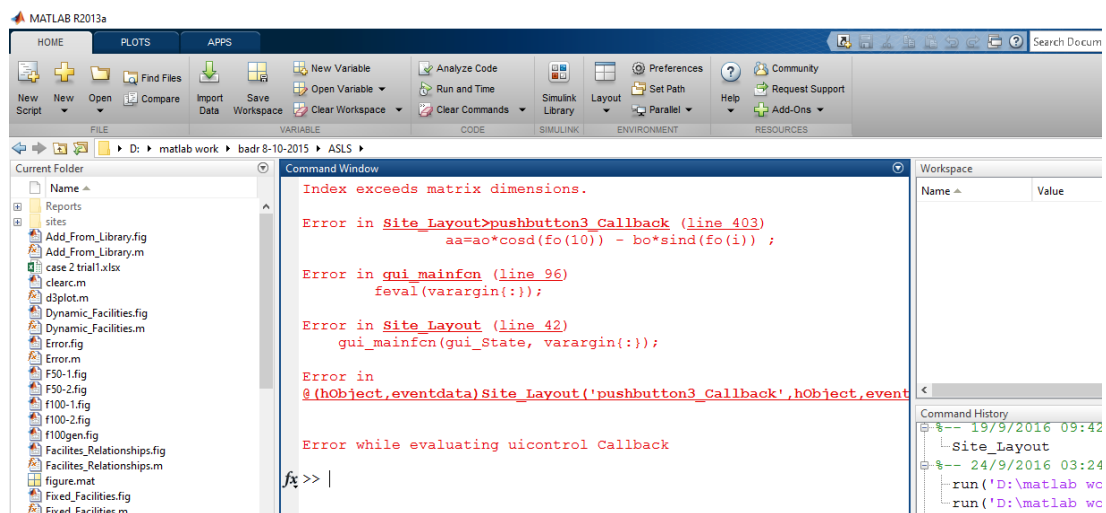


Figure (6. 33): Example of the errors occurred during the structural (white-box) test.

In phase two a functional (black-box) test is executed to examine the functional aspects of ASLS. Due to the large number of functions that the ASLS is capable to execute which needs a large number of functional tests to cover them, the functional testing executed in parallel with the validation process. The ASLS performance and results were observed during the simulation experiment of the validation process to examine its completeness and performance. The observation process for the ASLS

performance and results continued until the validation process finished to checking if there any problems occurred. In fact, no problems in the ASLS performance and results occurred during the tests. Accordingly, the ASLS completeness and performance have been verified.

### **6.7.2. The User Trial**

Evaluating the ASLS usability, functionality and user acceptability will be done through a controlled experiment in terms of a user trial method as mentioned before in chapter 4. The users' trial data collection and analysis methods that utilized to examine the ASLS usability, functionality and user acceptability are organised in two phases as discussed in the following sections.

#### **i. Phase 1 – Usability test (Questionnaires)**

##### **a) Data Collection**

The System Usability Scale (SUS) questionnaire is used for first phase of the user's trial data collection to examine the usability of the ASLS as mentioned before in section 4.6. The respondent has to take the chance to use the system in order to be able afterwards to use the SUS scale and before any discussion occurs about the system. Immediate responses are required to be recorded by respondents in order to avoid thinking about items for a long time. All the items should be checked by respondents but in case of not being able to respond to a particular item, they should mark the centre point of the scale (Brooke, 1996).

A brief idea of the purpose of the ASLS should be clarified to the respondents and then the set of tasks which are required to perform with the system by the Evaluator. Evaluator is also employed the procedure of “think aloud,” followed by an interview. Baillie and Schatz (2006) introduce the Think aloud as a process used during

evaluations in which the evaluator encourages the users to talk and discuss freely the problems they have with the system. Using this technique allows the users to consider themselves as collaborators in the evaluation and not simply as experimental subjects. Moreover, it enables the evaluator to ask the users some questions about the system. Dix, Finlay, Abowd, and Beale (1998) state that this form of evaluation consists of two advantages: the user can criticise the system, and the evaluator can discuss points of confusion at the time they occur and so increase the effectiveness of the approach for identifying problem areas.

The respondents are given an example as shown in appendix (B) in order to be able to execute a set of tasks as given below.

**Task 1:** Open the ASLS through MATLAB software.

**Task 2:** Input data for a new project.

**Task 3:** Open and edit an old project.

**Task 4:** Transfer data between two different projects.

**Task 5:** Run the ASLS.

The usability test is formulated to measure three aspects which are effectiveness, efficiency and satisfaction.

- Effectiveness: task completed successfully.
- Efficiency: the time taken to complete a task.
- Satisfaction: questionnaires result analysis.

To measure the efficiency of a completed task, the time taken from a user to complete this task (from the time that user is asked to start, to the time the task completed) must

be less than the expected time. The expected time is the time that estimated from pre-tests to complete the task. Bevan (2007) clarifies that the maximum time allowed to users before they are categorised as having failed should be at least three times the expected time. Table (6.10) presented the assigned time for each task with the expected time.

Table (6. 10): Allocated time for tasks.

<b>Tasks</b>	<b>Expected time in minutes</b>	<b>Assigned time in minutes</b>
Task 1	1	3
Task 2	6	18
Task 3	4	12
Task 4	2	6
Task 5	1	3

Each of the previously mentioned tasks is assigned a maximum amount of time to achieve its aim. All the questionnaires respondent responses are recorded and reported. In the next section, the analysis of data obtained from the questionnaires is analysed using three different methods as mentioned before in section 4.6.

#### b) Data Analysis

##### 1) Method 1 – Goal Achievement

To test the ASLS effectiveness and efficiency, a maximum amount of time is assigned for the SUS questionnaire respondents to successfully complete each task as set out in criteria in table (6.14). Figure (6.34) presents the goal achievement of the respondents. All the respondents have completed Tasks 1, 3 and 5 successfully within the assigned time. 80% of the respondents have completed Tasks 2 and 3 within the assigned time. Only 20% of the respondents have completed the Tasks 2 and 4 out of the assigned time. It demonstrates that high efficiency of the ASLS in terms of its usage and

functionalities. Furthermore, all the respondents have completed the tasks in the usability tests. It indicates the ASLS effectiveness.

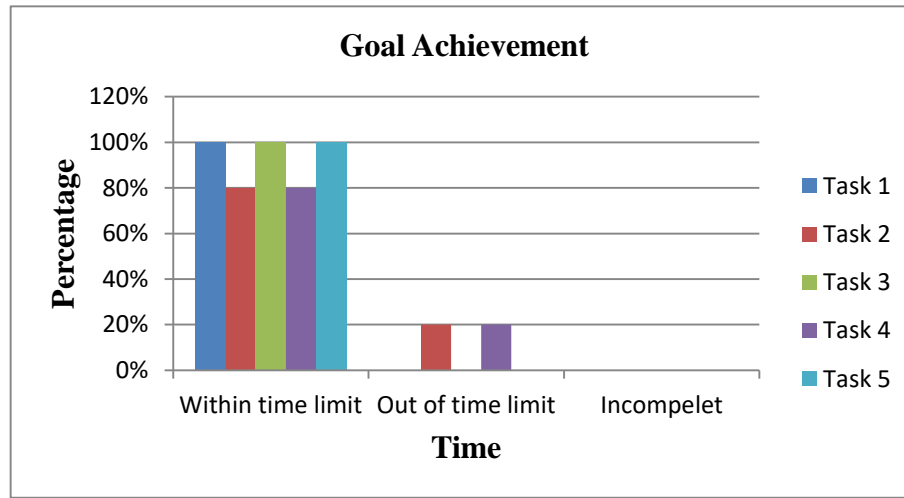


Figure (6. 34): Goal achievement by time.

The next section demonstrates the data analysis for the user's satisfaction using the total score method.

## 2) Method 2 – Total Score

The SUS score of the 5 users is calculated by summing up the score contributions from each item in order to test the user's satisfaction in using the ASLS. The score of each time contribution ranges from 0 to 4. The score contribution is the scale position minus 1 for items 1, 3, 5, 7, and 9 in the SUS, whereas for items 2, 4, 6, 8 and 10, the contribution is 5 minus the scale position. The total SUS score is calculated by multiplying the sum of the scores by 2.5 to get the overall value of SUS. A range of 0 to 100 in SUS score represents a composite measure of the overall usability of the system being studied (Brooke, 1996).

Figure (6.35) shows the results of the five users in the usability tests. All the questionnaires score above the 85% with 1 test scored 100%. These scores show the high satisfaction of using the ASLS between the users.



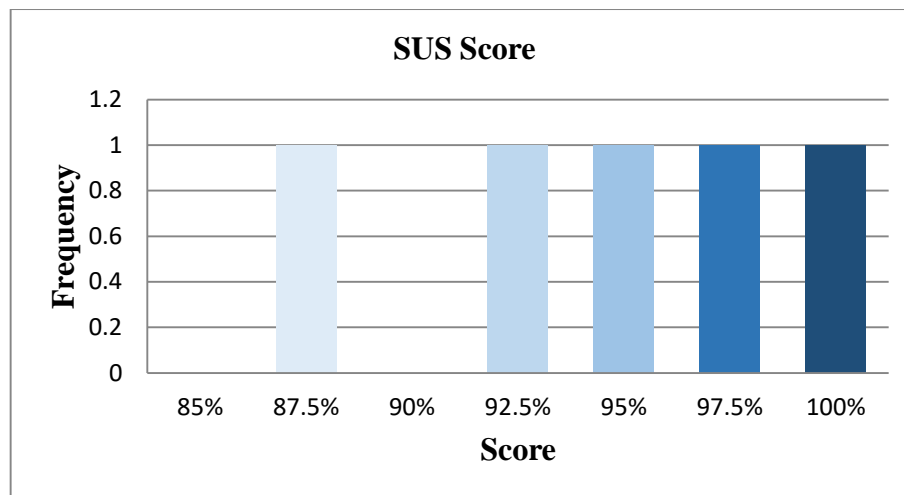


Figure (6. 35): Usability tests SUS score.

The next section demonstrates the data analysis for the user's satisfaction also, but based on its interface and functionalities by using another analysis method which is the maximum rating method.

### 3) Method 3 – Maximum Rating

To test the user's satisfaction in using the ASLS, the questionnaires result is converted to percentages by dividing each score by the maximum score possible on that scale. So, for example, a rating of 3 on SUS is converted to a percentage by dividing that by 5 (the maximum score for SUS), giving a percentage of 60% (Tullis & Stetson, 2004). The frequency distributions of the ratings on each questionnaire is converted to percentages as described above, are shown in figure (6.36). The higher frequencies of maximum rating in the SUS responses demonstrate that users are satisfied with the ASLS in terms of its interface and functionalities.

The analysis of data obtained from the questionnaires reveals the ASLS usability in terms of effectiveness, efficiency and satisfaction. The next section describes phase two of the users' trial that examines the ASLS functionality and user acceptability.

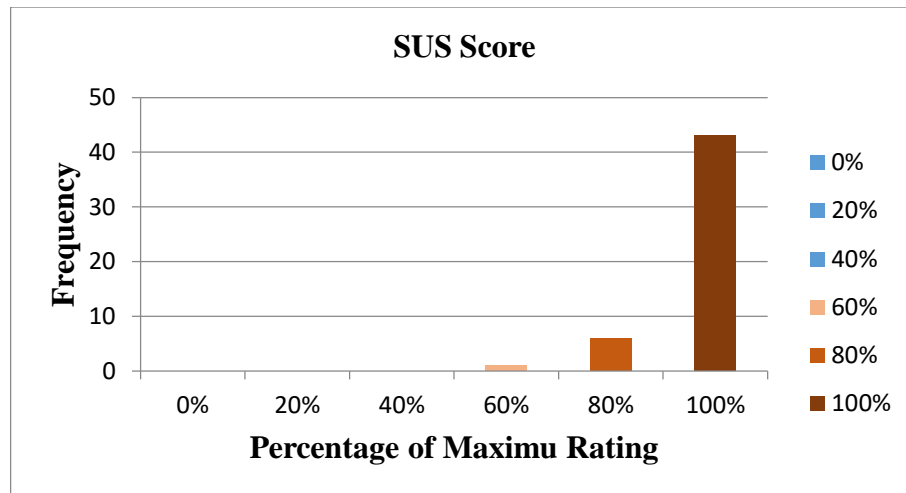


Figure (6. 36): Maximum rating in SUS questionnaire.

## ii. Phase 2 - Functionality and user acceptability tests (Interviews)

### a) Data Collection

Most user trials involve some form of interviews as a way of asking users their general opinion of the user trial and system (McClelland, 1995). In this second phase, the semi-structured interview is used for the data collection to examine the functionality and user acceptability of the ASLS based on two sets of questions as mentioned before in section 4.6. The first set aimed at evaluating ASLS functionality and whether it met the end users' requirements which was discussed before in chapter 3. While, the second set aimed at evaluating the ASLS acceptability as mentioned before in section 4.6. Accordingly, the ASLS user acceptability will be examined based on whether it meets the end users' requirements and its user acceptance.

In this phase, the same users who participate in the first phase of user trial as mentioned in the section 4.6 are interviewed. User interviews follow the usability tests carried out with SUS questionnaires. All user interviews results are recorded and reported to be ready for the analysis process as explained in the next section.

## b) Data Analysis

The user interviews results are analysed using a combination of coding and interpretation. Coding is used to organise the raw textual data that is highly unstructured since the interviewees referred to the same variable in various questions. Coding is the process of identifying one or more discrete passage of text or other data items that cover the same theoretical or descriptive idea (Gibbs, 2002). To analyse properly, attaching codes to data and generating concepts enable the researcher to review what the data is saying. Furthermore, coding is a mixture of data reduction and data complication since it is used to break up and segment the data into simpler, general categories and is used to expand and tease out the data in order to formulate new levels of interpretation (Coffey & Atkinson, 1996). Because of the coding principles, the textual data in each question was grouped into main categories by the researcher. The objective was to capture common results (answers), which formed a basis for the interpretations as the analysis of the interviews results will be completed by the interpretation of the results as mentioned before in section 4.6. The coding of the five interviewees is introduced in table (6.11).

Table (6. 11): The coding of the interviewees.

<b>Code</b>	<b>Job</b>
A	Professor (consultant)
B	Professor (consultant)
C	Project Manager
D	Project Manager
E	Site Engineers

The aim of the next sections is to examine the ASLS functionality and user acceptability based on the data obtained from the semi-structured interview questions, which are categorised under two sets as follow:

### 1) Questions set 1

The aim of this set is to assess the ASLS functionality and whether it meets the end users' requirements. To achieve this aim, the interviewees were asked the five questions which presented before in section 4.6. Table (6.12) introduces the interviewees answers of the first set questions which coded and grouped into main categories by the researcher.

Table (6. 12): The interviewees' answers of the first set questions.

Question 1	Interviewee	Answers	Answer Code		
			Features	Capabilities	
What motivates you to use the ASLS?	A	"It's user friendly interface"	1		
	B	"It's optimization capabilities"		2	
	C	"It's very easy in exchanging data between projects"	1	2	
	D	"It's easy in inputting data"	1		
	E	"It's very easy to use and give great results"	1	2	
Question 2	Interviewee	Answers	Answer Code		
			Yes	No	
Do you perceive the benefits of the ASLS?	A	"Definitely"	1		
	B	"Yes, it makes the site layout planning easy task"	1		
	C	"Yes, it saves too much time"	1		
	D	"Yes, it saves time and effort"	1		
	E	"Sure"	1		
Question 3	Interviewee	Answers	Answer Code		
			Yes	No	
Do you find the ASLS ease the site layout planning workload?	A	"Yes, sure"	1		
	B	"Yes, but I think this depends on the user also"	1		
	C	"Yes, of course"	1		
	D	"Yes, I think it decreases the workload into few steps instead doing them manually"	1		
	E	"Sure"	1		
Question 4	Interviewee	Answers	Answer Code		
			Yes	No	Other
Did you find the ASLS fulfilled what the user needs in such program?	A	"I think so"	1		
	B	"Definitely"	1		
	C	"Yes, but I think if it could calculate the cost of mobilization it will be a powerful addition to the users"	1		
	D	"Yes I think I will not ask for more in such program"	1		
	E	"I don't know"			3
Question 5	Interviewee	Answers	Answer Code		
			Yes	No	
Did you find the generated solution by the ASLS efficient in your opinion?	A	"Yes it is, but I do not know how it will perform in large-scale projects"	1		
	B	"yes, but I think that it will be difficult to judge its overall efficiency based on this example"	1		
	C	"It was very good, similar to what I would have done in site"	1		
	D	"Yes, very efficient"	1		
	E	"Yes, I think"	1		

The following sections will inspect, discuss and interpret the interviewees' answers for each question to assess the ASLS functionality and whether it meets the end users' requirements.

The first question was ***What motivates you to use the ASLS?*** It was found that all interviewees were really motivated to use the ASLS due to its features and capabilities as discussed and interpreted next. Interviewee (A)'s answer "*it's user friendly interface*", demonstrated that the ASLS interface was functional and user friendly in use. Furthermore, it revealed that the ASLS met one of the end users' requirements mentioned before in chapter 3. According to Interviewee (B) "*It's optimization capabilities*", his answer clearly indicated that the ASLS had functional optimization capabilities in locating the site facilities. As for Interviewee (C) "*It's very easy in exchanging data between projects*", his answer showed the ASLS functionality in exchanging data between projects based on its library. Regarding Interviewee (D) "*It's easy in inputting data*", his answer revealed the ASLS functionality in inputting the project data as well as its made the ASLS met another requirements of the end users' requirements mentioned before in chapter 3. Interviewee (E)'s answer "*It's very easy to use and give great results*", demonstrated that the ASLS had practical features and capabilities which facilitate its use and generate suitable solutions.

The second question was ***Do you perceive the benefits of the ASLS?*** It was found that all interviewees were really felt that they perceived the benefits of the ASLS as it saved time and effort as discussed and interpreted next. As for Interviewee (A)'s response "*Definitely*", it confirmed on perceiving the benefits of the ASLS. According to Interviewee (B) "*Yes, it makes the site layout planning easy task*", his answer argued the ASLS functionality in executing the site layout planning task. Regarding Interviewee (C) "*Yes, it saves too much time*", his answer demonstrated the ASLS

functionality in saving time during the site layout planning. Interviewee (D)'s answer *“Yes, it saves time and effort”*, clearly indicated the ASLS functionality in saving time and efforts in executing a site layout planning. Through Interviewee (E)'s answer *“Sure”*, the benefits of the ASLS were made clear. Furthermore, these previous answers confirmed that the ASLS functionality in facilitating the site layout planning which compatible with the end users' requirements mentioned before in chapter 3.

The third question was ***Do you find the ASLS ease the site layout planning workload?***

It was found that all interviewees agreed that the ASLS will really ease the site layout planning workload as discussed and interpreted next. According to Interviewee (A) *“Yes, sure”*, his answer confirmed that the ASLS ease the site layout planning workload. Going to Interviewee (B)'s response *“Yes, but I think this depends on the user also”*, it demonstrated that the ASLS facilitated the site layout planning workload but he thought that the user should have an acceptable knowledge in advance with the ASLS usage by accessing its manual. For Interviewee (C) *“Yes, of course”*, his answer revealed that the ASLS eased the site layout planning workload. As for Interviewee (D) *“Yes, I think it decreases the workload into few steps instead doing them manually”*, his answer clearly indicated the ASLS functionality in decreasing the site layout planning workload into few steps. According to Interviewee (E) *“Sure”*, his answer showed that the ASLS effective in easing the site layout planning workload. Furthermore, these previous answers confirmed that the ASLS functionality in easing the site layout planning workload and offering a detailed help manual which was compatible with the end users' requirements mentioned before in chapter 3.

The fourth question was ***Did you find the ASLS fulfilled what the user needs in such program?*** It was found that four of interviewees agreed that the ASLS fulfilled the user needs in such program. Whereas the fifth interviewee was unable to govern this

question based on lack of knowledge with the user need as discussed and interpreted next. ASLS fulfilled the user needs in such program was clear through Interviewee (A)'s answer *"I think so"*. According to Interviewee (B) *"Definitely"*, his answer clearly indicated that the ASLS features and capabilities satisfy the end user requirements. Interviewee (C)'s answer *"Yes, but I think if it could calculate the cost of mobilization it will be a powerful addition to the users"*, revealed that the ASLS compatible with the user needs in such program but he thought that if the ASLS has the ability to calculate the cost of mobilization, it will be a powerful addition to the users. This thought was distinct indeed and will be taken into consideration as a future work for this research. As for Interviewee (D)'s response *"Yes I think I will not ask for more in such program"*, it confirmed that the ASLS functionality in offering features and capabilities fit with the user needs. According to Interviewee (E) *"I don't know"*, his answer did not state that the ASLS failed to fulfill the user needs but showed his inability to govern this question based on lack of knowledge with the user need. Although one of the interviewees was unable to govern this question, the rest of the interviewees answers showed that the ASLS fulfilled the user need, this achieved by satisfying all the end users' requirements collected in chapter 3 in developing the ASLS.

The fifth question was ***Did you find the generated solution by the ASLS efficient in your opinion?*** It was found that all interviewees were agreed that the ASLS was efficient in developing a site layout for the examined example as discussed and interpreted next. Regarding Interviewee (A) *"Yes it is, but I do not know how it will perform in large-scale projects"*, he revealed the ASLS functionality in developing efficient site layout for the examined example but he also wondered about the ASLS efficiency in large-scale projects. Concerning Interviewee (B) *"yes, but I think that it*

*will be difficult to judge its overall efficiency based on this example*”, his answer indicated that the generated solution by the ASLS for the examined example, but he also argued the difficulty in judging the ASLS overall efficiency in generating a site layouts based the examined example. Interviewee (A) and (B) were briefed on the ASLS results in validation process to demonstrate its capabilities in different project sizes and they were really happy with the result achieved. Interviewee (C)'s answer *“It was very good, similar to what I would have done in site”*, proved the ASLS functionality in developing efficient site layout and its similarity to what is done in real sites. According to Interviewee (D) *“Yes, very efficient”*, his answer confirmed the ASLS efficiency in executing the site layout planning. According to Interviewee (E) *“Yes, I think”*, his answer argued the ASLS functionality in generating an efficient site layout plan. Furthermore, these previous answers confirmed the ASLS functionality in developing efficient site layouts which was compatible with the end users’ requirements mentioned before in chapter 3.

Based on the aforementioned answers, it can be easily deducing that users understand the system, its purpose and its benefits. Furthermore, these answers clearly indicate that the ASLS is functional and provides the end users’ requirements in such automated system as discussed in chapter 3. However, it is necessary to understand the user acceptability of the ASLS as it will be discussed in the next section.

## 2) Questions set 2

The aim of this set is to assess the ASLS user acceptance. To achieve this aim, the interviewees were asked the three questions which presented before in section 4.6. Table (6.13) introduces the interviewees answers of the second set questions which coded and grouped into main categories by the researcher.



Table (6. 13): The interviewees' answers of the second set questions.

Question 1	Interviewee	Answers	Answer Code		
			Yes	No	
Do you find the ASLS ease your work load?	A	"sure"	1		
	B	"I think it does but it also depends on the availability of data"	1		
	C	"I think it is because it saved too much time which is very important"	1		
	D	"Definitely"	1		
	E	"Yes"	1		
Question 2	Interviewee	Answers	Answer Code		
			Yes	No	
Do you think the use of ASLS will improve the efficiency of site layout planning?	A	"I think so"	1		
	B	"Definitely"	1		
	C	"Sure, because it is concerned with improving multiple factors"	1		
	D	"sure"	1		
	E	"I think it will"	1		
Question 3	Interviewee	Answers	Answer Code		
			Yes	No	Other
Are you willing to use the ASLS?	A	"Yes of course"	1		
	B	"Maybe, it will depend on the project time and type"			3
	C	"Yes definitely I will use it"	1		
	D	"Yes and I will recommend it to my colleagues"	1		
	E	"Definitely"	1		

The following sections will inspect, discuss and interpret the interviewees answers for each question to assess the ASLS users' acceptance.

The first question was *Do you find the ASLS ease your work load?* It was found that all interviewees were agreed that the ASLS ease their work load as discussed and interpreted next. According to Interviewee (A) "*sure*", his answer demonstrated that the ASLS will ease his work load. Interviewee (B)'s answer "*I think it does but it also depends on the availability of data*", argued that the ASLS eased his work load but he also thought that he will depend on the availability of data. As for Interviewee (C) "*I think it is because it saved too much time which is very important*", his answer revealed that the ASLS eased the work load as it saved time. According to Interviewee (D) "*Definitely*", his answer confirmed that the ASLS will ease his work load. Concerning Interviewee (E) "*Yes*", his answer clearly indicated that the ASLS will facilitate the work required from him.

The second question was ***Do you think the use of ASLS will improve the efficiency of site layout planning?*** It was found that all interviewees were agreed that the ASLS will improve the efficiency of site layout planning as discussed and interpreted next. According to Interviewee (A) *"I think so"*, his answer confirmed that the ASLS will improve the efficiency of site layout planning. Interviewee (B)'s answer *"Definitely"*, argued the ASLS efficiency to improve the site layout planning. Regarding Interviewee (C) *"Sure, because it is concerned with improving multiple factors"*, his answer demonstrated that the ASLS did as it improved multiple factors in executing the site layout planning task. Concerning Interviewee (D) *"sure"*, his answer clearly indicated the ASLS will improve the efficiency of site layout planning. Concerning Interviewee (E) *"I think it will"*, his answer revealed that the benefits of the ASLS in improving the site layout planning.

The third question was ***Are you willing to use the ASLS?*** It was found that four of interviewees were totally agreed that they will use the ASLS. Whereas the fifth interviewee was agreed but based on the project time and type as discussed and interpreted next. According to Interviewee (A) *"Yes of course"*, his answer confirmed that he will use ASLS. Concerning Interviewee (B) *"Maybe, it will depend on the project time and type"*, his answer demonstrated that he will use ASLS if the project time and type allow. As for Interviewee (C) *"Yes definitely I will use it"*, his answer revealed that he will definitely use ASLS. Interviewee (D)'s answer *"Yes and I will recommend it to my colleagues"*, clearly indicated that the interviewee will use and recommend the ASLS. According to Interviewee (E) *"Definitely"*, his answer showed the interviewee high acceptability to use the ASLS.

The analysis of the interviewees answers revealed that the ASLS acceptable to use and efficient as it saves time. Moreover, one of the interviewees will recommend it to his colleagues.

## **6.8. SUMMARY AND CONCLUSIONS**

The main aim of this chapter was to demonstrate the post-development stage carried out on the ASLS. The following conclusions were reached as a result of the post-development stage:

- The ASLS capabilities covered all the end user' requirements and offered number of new features and functions.
- The ASLS implementation process was done through three steps: 1) ASLS access; 2) ASLS data input or edit; 3) ASLS run.
- The results of the tuning process confirmed that the values of the genetic algorithms parameters effected on the performance of the optimization process.
- The ASLS will facilitate the site layout planning work in the Egyptian sites for the international and local users based on its main database library.
- The ASLS validation process results proved its accuracy and effectiveness as well as the success of the dynamic search process introduced in this research.
- The ASLS evaluation process results demonstrated its functionality, completeness, performance, usability and user acceptance as follow:
  - i. The functional (black-box) and structural (white-box) tests results verified the ASLS completeness and performance.
  - ii. The analysis of data obtained from the questionnaires indicated the ASLS usability in terms of effectiveness, efficiency and satisfaction.

- iii. The analysis of the interviewees answers revealed that the ASLS acceptable to use and efficient as it saves time.

The following chapter will end this research by introducing the discussion and final conclusion.

## **CHAPTER 7**

### **DISCUSSION AND CONCLUSION**

#### **7.1. INTRODUCTION**

This research has successfully developed an automated dynamic site layout planning system (ASLS) for the construction industry. Therefore, the main aim of this chapter is to discuss the research, assessing it according to the original objectives. Then the chapter will demonstrate the research main finding. The conclusions drawn are presented and the contributions to knowledge made by this research outlined. Limitations of the research study will also be made in this chapter. Recommendations for future work will be discussed later in this chapter.

#### **7.2. DISCUSSION**

Although the construction site layout planning was recognized as a critical step in construction planning and presented a particularly interesting area of research, it did not have a complete solution for its problems until now. To date, the construction industry is still struggling to develop integrated systems in which software packages can exchange information and work together to solve the site layout planning problems. This was due to the fact that the existing automated systems still had shortcomings and limitations or not realistic and did not offer the end users' requirements in such system as mentioned before in chapters 2 and 3. This encouraged the development of new automated system with capabilities to cover the shortcomings and limitations of existing systems and meet the end users' requirements.

Therefore, this research aimed at developing an automated dynamic site layout planning system for construction sites that could generate an optimal and efficient site layout to enhance the performance in construction site. In addition, it will reduce negative effects of the site layout planning and filled the gap of the current practices to assist in the success of construction sites. Specific research objectives helped to achieve this aim. These research specific tasks along with key findings are summarized below putting into consideration the original research objectives:

**OBJECTIVE 1 - Develop an understanding of site layout planning within the construction industry, explore its current practices and challenges.**

To achieve this objective, an understanding to the state of the art of site layout planning in construction industry and research was essential. This motivated the work in Chapter 2 to develop an understanding of the site layout planning criteria and concepts. To aid this work, a detailed review of the site layout planning definitions, factors, challenges and current practices was developed. This review assisted in synthesizing definition for the site layout planning to be the base for designing the proposed automated system and highlighted the positive and negative effects of it on the construction projects. Furthermore, the review clarified the automation process and its benefits in executing the site layout planning

The chapter has shown that there are a number of definitions for construction site layout planning, however, this research defined the construction site layout planning task as (finding the optimal layout for construction sites according to facilities duration, constraints and objective's demand by each project). The chapter also revealed that the site layout planning was one of the construction industry problems that needed more attention and development. Due to the currently implemented

method of the site layout planning task in construction sites which led to negative impact on the safety, productivity, cost, time, waste materials and surrounding environment of construction projects. One important conclusion drawn was that the efficient layout planning of a construction site was fundamental to any successful project undertaking. Another important conclusion was that automated systems can be considered as the most effective methods to develop an efficient site layout as they fully covered all concerns that cannot be taken into account by manual methods. Therefore, there was a need to review the existing automated site layout planning.

**OBJECTIVE 2 - Explore existing automated systems to define their limitations, shortcomings and the successful utilizations that can be incorporated within the proposed automated system.**

To help set recommendations for developing a new automated site layout planning, the existing automated site layout planning were reviewed in Chapter 2 also. Literature, however, shown that there was a lot of automated systems existed. The main conclusion drawn from this review was that the existing automated systems had a lot of limitations and shortcomings that needed to be covered. These limitations and shortcomings were identified as a single objective, integrating with regular facilities and site areas only, 2D site layouts representation, inefficient approaches to reflect the dynamic nature of construction sites, ignoring space reuse and facilities relocation, equal area space search, generating static layout, did not cover end users' requirements, being built on real factors measured from sites, highly complex for users, ignoring the user interaction, and lacking of flexibility in the system design. Consequently, they cannot be applied to other cases, but only the case they were designed for. Therefore, there was a role to improve the site layout planning by

developing new automated system that covered the existing automated systems had a lot of limitations and shortcomings.

**OBJECTIVE 3 - Collect and capture the site layout planning circumstance and end users' requirements from real Egyptian construction sites.**

Chapter 2 findings directed the research to initiate the work in Chapter 3, to assess the site layout planning in the real Egyptian construction sites for more clearly formulate an explicit and precise research problem and setting the proposed automated site layout planning system tool and technique. Chapter 3 developed a quantitative study (surveys in terms of questionnaires) based on the methodology described in chapter 4 in order to collect and capture the importance, objectives, implementation methods, problems, effects, automation, end users' requirements, facilities and facilities relations of site layout planning from real Egyptian construction sites. The conclusions drawn from this study are summarised below:

- The population sample confirmed the importance of the site layout planning task as any other projects' task.
- The efficient site layout planning could multiple projects' objectives such as minimizing cost and time, maximizing safety and protecting the surrounding environment. However, responses given by the sample generally indicated that the real construction sites interest in minimizing the projects' cost and time and maximizing the projects' safety more than protecting the projects' surrounding environment.
- The most appropriate stage – of the project's life cycle –for implementing of the site layout planning task is the planning stage.
- The quality of the site layout plan is affected by the stage it is implemented in.



- Responses given by the sample indicated that the most suitable person to execute the site layout planning task is the project manager.
- The information needed to develop a site layout plan in real sites are the project schedule, site boundary and drawings, needed facilities, project size and project budget.
- The high scores given to determining the temporary facilities location stage as the most difficult stage in implementing the site layout planning.
- Responses given by the sample indicated that the site layout plan need to be updated with the project's duration.
- Inefficient site layouts planning may lead to problems in construction sites which impact negatively on the projects performance.
- The highest proportion of participants did not use an automated site layout planning systems before. However, they also were supportive to such systems as they thought it will help in developing more efficient site layouts.
- The Egyptian sites end users' requirements which needed to offer in any new automated system are:
  1. a user friendly interface to facilitate the usage and inputting needed information.
  2. a data bank contains samples of old project and varieties of facilities.
  3. the ability to update the layout with the project progresses.
  4. a 3D representation for facilities and layouts.
  5. a detailed help menu.
  6. a dynamic modelling approach.
  7. multi-objective function.

The literature reviews and the quantitative study findings led to identifying the MATrix LABoratory (MATLAB) and Genetic Algorithm (GA) as the suitable tool and technique to overcome the site layout planning limitations and shortcomings as well as offer the end users' requirements. Furthermore, it assisted in formulated the suitable structure and characteristics for the development of the proposed system in chapter 5 in order to function efficiently and impact positively on construction sites.

**OBJECTIVE 4 - Select a suitable research methodology for developing the proposed dynamic automated site layout planning system.**

To achieve this objective, a review to the various research methodologies available for undertaking this research was developed in chapter 4. The “design science” found to be the most appropriate research methodology for this research. The design science research methodology acknowledged IT as a component of improving and developing artifacts for the development of better solutions. This chapter also elaborated and justified the process involved in the theoretical groundwork related to the adoption of this research philosophies, approaches and strategies as well as methods and techniques for data collection and analysis. Based on this understanding the automated system was developed in three stages:

- The pre-development stage which identified the research problem awareness and the solution suggestion.
- The development stage which entailed the system analysis and design then the system development.
- The post-development stage which focused on the system validation and evaluation processes.

**OBJECTIVE 5 - Define the structure and characteristics of the proposed automated dynamic site layout planning system.**

The literature review findings directed the research to initiate the work in Chapter 5, to identify the structure and characteristics used to develop the proposed multi objective dynamic automated site layout planning system. This chapter demonstrated that the proposed automated system will implement and integrate into four main components in order to provide the targeted features, functions, capabilities and end users' requirements mentioned in chapters 2 and 3. The chapter also revealed that the methods utilize in the existing automated systems to reflect the dynamic nature of the construction sites had some drawbacks impeded it for generating an optimal site layout. So a new method introduced in this chapter for the dynamic search process to generate an optimal site layout that reflected the dynamic nature of construction sites and provided improvements to the existing search methods. Chapter 5 also explained the Multi Objective Optimization functions (MOO) implemented to optimize the dynamic layout problems to mimic the objective of real sites. Three congruent objective functions were employed to generate optimal dynamic layouts for construction project in order to 1) minimize the cost and time of the construction projects; 2) improve the safety level; 3) minimize the harmful effect of construction activity on the surrounding environment. It is worth mentioning that this research has introduced, for the first time, an objective function for the environmental concerns which is the third objective function.

Furthermore, this chapter explained in detail the characteristics of the proposed automated system as summarized below:

- The proposed automated system will represent and analysis the site space as a continuous space and allows the facilities to be located anywhere in the construction site. Furthermore, it will represent and analysis any regular or irregular site shapes defined by the user.
- Represent and analysis any regular or irregular facilities shapes defined by the user. Furthermore, the site facilities will be divided to five groups based on the way they are involved in the search process. The proposed automated system will be capable to orient the fixed facilities, obstacles and protection zones with any given angles defined by the user as well as the static and dynamic facilities with angles  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $270^\circ$  only.
- Utilize any number of project stages defined by the user according to his/her experience, need and vision.
- Use three proximity weights in order to represent the interaction closeness relationship between facilities for the three desired objectives.
- Consider the real distance between facilities in determining the first objective function, while it will consider the Euclidean distance in determining the second and third objectives.
- Set the boundary and overlap constraints as the default constraints which used to govern the process of positioning the facilities, while the minimum distance that added by the user as the optional constraint which used to provide safety buffer distance around facilities shape.

These characteristics was used to develop the automated system to generate optimal dynamic layouts for construction project in order to cover most of existing systems

drawbacks and limitations as well as offer the end users' requirements. The chapter also argued the proposed automated system expected positive impacts on the construction industry in terms of: (1) improving the site layout and space planning (2) maintaining the construction projects cost and time; (3) improving the overall safety of construction sites; and (4) protecting the surrounding environment.

**OBJECTIVE 6 - Develop, validate and evaluate the dynamic automated site layout planning system and draw a set of recommendations for improving automated site layout planning systems.**

Chapter 5 introduced the structure and characteristics of the automated system that considered a prerequisite to develop any computer aided problem solving system. This directed to the automated system development then tuning the genetics algorithms parameters to generate optimal site layouts. Finishing the developing of the automated system ended the development stage. Therefore, chapter 6 demonstrated the post-development stage adopting the methodology described in chapter 4. The post-development stage focused on the automated system validation and evaluation processes. The validation process executed through a simulation experiment on two construction projects based in Egypt as two case studies to examine the ASLS accuracy and effectiveness.

The first case study was a small-scale project which was a private residential villa located in Borg El Arab, Alexandria, Egypt. The site area = 4148 m<sup>2</sup> and the project's budget = 1.5 million EGP. The ASLS validated through this case by three trials. The first trial was setup for validating the ASLS accuracy while the other two trials were setup for validating the ASLS effectiveness. The second case study was a large-scale project which was an educational building located in Abu Kir, Alexandria, Egypt. The

site area = 5761 m<sup>2</sup> and the project's budget = 30 million EGP. The ASLS validated through this case by three trials. The first trial is setup for validating the ASLS accuracy while the other two trials were setup for validating the ASLS effectiveness. Due to the construction projects scope, the validation process for the ASLS effectiveness test executed based on one scenario which was cost/time minimization objective.

The weights of solutions calculated by the ASLS for the first trials in both case studies were quite similar to the manual calculations for the weights of the original layout developed by both project's managers. These results proved the ASLS accuracy in weight calculation. The generated solutions by the ASLS for the rest of trials in both case studies achieved a reduction in layouts weight's than the original layout weight developed by both project's managers. Furthermore, the selected solution by ASLS in the third trial of second case study was the lowest layout weight. It was the stage layout not the entire project layout. This selection proved the success of the dynamic search process introduced in this thesis. These results proved that the ASLS effectiveness in developing optimal site layouts for construction projects. However, these result generated based on cost/time minimization scenario so if this scenario changed the result may change also. Therefore, this system is considered as a solution explorer that may generate better solution or test all solution for the best performance in sites.

The second scope of the post-development stage was the evaluation process. The ASLS has been evaluated for its functionality, completeness, performance, usability and user acceptance through functional (black-box) and structural (white-box) and users' trial. The functional (black-box) and structural (white-box) tests results verified the ASLS completeness and performance. The users' trial data collection and analysis methods were organised in two phases questionnaire and interviews. The usability of

the system was measured by the questionnaires. The functionality and user acceptance of the system were examined by the user interviews. Five users have participated in the user trial due to three different sets of user profiles. Data from questionnaires and interviews were analyzed. The analysis of data obtained from the questionnaires indicated the ASLS usability in terms of effectiveness, efficiency and satisfaction. The analysis of the interviewees answers revealed that the ASLS acceptable to use and efficient as it saves time. The recommendations drawn for improving automated site layout planning systems will be discussed later in section 7.7.

### **7.3. MAIN FINDINGS**

Based on the findings outlined in the preceding chapters of the thesis, the following main finding can be drawn:

- Site layout planning is one of the construction industry problems that need more attention and development.
- Efficient layout planning of a construction site is fundamental to any successful project undertaking.
- Site layout planning is often ignored or overlooked in construction sites which leads to negative impact on the safety, productivity, cost, time, waste materials and surrounding environment of construction projects.
- Automated systems can be considered as the most effective methods to develop an efficient site layout as they fully cover all concerns that cannot be taken into account by manual methods. However, the available automated systems have a lot of limitations and shortcomings.

- The Egyptian sites end users' requirements which needed to offer in any new automated system are:
  - i. a user friendly interface to facilitate the usage and inputting needed information.
  - ii. a data bank contains samples of old project and varieties of facilities.
  - iii. the ability to update the layout with the project progresses.
  - iv. a 3D representation for facilities and layouts.
  - v. a detailed help menu.
  - vi. a dynamic modelling approach.
  - vii. multi-objective function.
- There are a lot of tools and techniques to develop an automated system, however the MATLAB program and the Genetic Algorithms optimization technique are the most suitable to overcome the site layout planning limitations and offer the end users' requirements.
- The existing automated systems have some limitations in their approaches introduced to reflect the site changes (dynamic nature) over the project duration that may lead to inefficient site layouts.
- There is a need to improve the site layout planning by developing new automated system to generate more efficient site layout taking into consideration the end user' requirements.



- Design science methodology is a suitable research methodology for developing IT applications including automated dynamic site layout planning system.
- The developed automated dynamic site layout planning system (ASLS) implement and integrate into four main components in order to provide the targeted features, functions, capabilities and end users' requirements.
- The developed automated dynamic site layout planning system (ASLS) offer an objective function for protecting the construction sites surrounding environments from the harmful effects that produced from site activities.
- The developed automated dynamic site layout planning system (ASLS) is an effective tool for generating site layouts for the construction sites.

## **7.4. CONCLUSION**

The aim of this research has been achieved by developing an automated dynamic site layout planning system (ASLS) that generated optimal site layouts for construction site based on facilities' actual duration for the optimal use of available spaces in sites to reflect the dynamic nature of construction sites. The ASLS has been validated for its accuracy and effectiveness through two construction projects based in Egypt. Moreover, the ASLS was evaluated for its functionality, completeness, performance, usability and user acceptance through users' trial. However, this research has also concluded that:

- The automated systems were the most effective methods to develop an efficient site layout.

- MATrix LABoratory (MATLAB) and Genetic Algorithm (GA) were considered an effective tool and technique to develop an automated site layout planning system.
- The real sites circumstance, factors and end user's needs must be considered in developing automated site layout planning systems.
- The developed automated dynamic site layout planning system (ASLS) was effective in generating sites layout planning.
- The automated dynamic site layout planning system (ASLS) was expected to have positive impacts on the construction industry in terms of: (1) improving the site layout and space planning (2) maintaining the construction projects cost and time; (3) improving the overall safety of construction sites; and (4) protecting the surrounding environment.
- The automated dynamic site layout planning system (ASLS) capabilities covered all the end user' requirements and offered number of new features and functions.
- The automated dynamic site layout planning system (ASLS) facilitated the site layout planning work in the Egyptian sites for the international and local users based on its main database library.
- Dividing the project duration into successive stages with allowing facilities relocation may lead to better site layouts.
- The automated dynamic site layout planning system (ASLS) validation process results proved its accuracy and effectiveness in developing optimal site layouts for construction projects.

- The automated dynamic site layout planning system (ASLS) evaluation process results shown that the ASLS scored high in the usability tests and it was acceptable to work in the construction industry.

## **7.5. CONTRIBUTIONS TO KNOWLEDGE**

This research has been successful in identifying a number of barriers and enablers to produce dynamic automated system for construction sites, that benefited from the MATLAB program with its genetic algorithms toolbox capabilities and covered most of existing systems limitations. This research has therefore contributed to knowledge in the following ways:

### **7.5.1. Contributions to Theory:**

- Introducing the potential effects of site layout planning and identifying the ambidexterity of the site layout planning systems.
- Creating of an innovative dynamic space search method that reflected the dynamic nature of construction sites based on facilities actual duration.
- Formulation of a novel objective function that minimized the harmful effect of construction activity on the surrounding neighboring in order to grab attention to the environmental concern.
- Development of a Multi Objective Optimization functions (MOO) that allowed the simultaneous optimization of the construction cost, time, safety and environmental concern.

### **7.5.2. Contributions to Practice:**

- Formulation of novel automated dynamic site layout planning system that outperforms existing automated systems in generating global site layouts while

satisfying the layout constraints by offering number of new capabilities as follows:

- i. Covering the real sites circumstance and factors as well as users' needs.
- ii. Offering user friendly interface with huge user interaction in adjusting or adding data and in selecting the desired objective.
- iii. utilizing unlimited number of facilities and project stages.
- iv. Representing the site space as a continuous space to allow the facilities to be located anywhere in the construction site.
- v. Analyzing any regular or irregular site and facilities shapes.
- vi. Allowing for facilities to orient with angles options according to the user desire.
- vii. Utilizing facilities closeness relationship represented the user desire and calculated for the real interaction duration between facilities in site.
- viii. Calculating the real distance between facilities that represented the actual travel distances without neglecting the presence of obstruction between them.
- ix. Offering database library for storing and retrieving construction projects data and the generated optimal solutions.
- x. Generating 4D site layouts.

## 7.6. LIMITATIONS OF THE RESEARCH

This research successfully achieved its aim by developing automated dynamic site layout planning system (ASLS) to generate optimal site layouts for construction sites.

However, there are a number of limitations of this research listed below:

- The real sites layout circumstances and the automated system end users' requirements captured from Egyptian construction sites as Egypt was the only case study for this research. However, expanding the research case study to include more countries in collecting these data will improve the performance of the developed automated dynamic site layout planning system (ASLS) and offer a better chance for it to be adopted internationally.
- In order to minimize the ASLS solution searching time, the automated system is capable of orienting the fixed facilities, obstacles and protection zones with any given angles defined by the user. In addition to its capability of orienting the static and dynamic facilities to orient with angles options 0 °, 90 °, 180 ° and 270 ° only. However, expanding the capability to allow the orienting of the static and dynamic facilities with more angles options without increasing the solution searching time would improve the practicality of the automated system.
- Due to the construction projects scope and layouts execution method in Egypt (which only consider for the project cost/time and the Euclidean distance), the ASLS validation process was executed based on project cost/time minimization scenario only as well as the ASLS was programmed to considered the Euclidean distance as the actual travel distances between the site facilities.

- The ASLS was validated with two construction sites based in Egypt only. However, the ASLS could be validated with construction sites outside Egypt to increase the reliability of the automated system.
- The selected evaluation sample was limited to five practitioners including academic and industry experts. However, more practitioners could have been used in order to get better rounded opinion of the automated system.

## **7.7. RECOMMENDATIONS FOR FUTURE WORK**

The research has successfully achieved the aim of the research as set out in the chapter 1. However, there are a number of recommendations that can be made for future work to enhance the performance of the ASLS and maximizing the benefit of using it, as listed below:

- Although this automated system generated 4D layouts, the layout presentation could be enhanced by adding facilities element materials type (such as wood or bricks).
- Integrating the automated system with the Computer Aided Drafting (CAD) to read data directly from the construction drawings and represent the generated layouts on it.
- Exploring the potential for allowing to the static and dynamic facilities to orient with any angles not only with options 0 °, 90 °, 180 ° and 270 ° without increasing the solution searching time.
- Integrating the automated system with the Building Information Modelling (BIM) to facilitate the data exchange and provide the project managers/stakeholder with different scenarios of site layout that is compatible

with other project activities as well as expand the automated system space search process to include the proposed building area to give it the capabilities of locating facilities in this areas while the project progress.

- Exploring the potential for expanding the automated system capabilities to include the calculation of mobilization cost as recommended by the users' trail interviewees.
- Investigating the strategies to incorporate the optimization of the critical planning decisions of material procurement and site layout planning in order to minimize ordering, financing, stock-out and site layout costs.

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9) What type of information this person will need to develop a site layout plan?

.....  
.....  
.....

10) In your opinion, what is the most difficult stage of the site layout planning task?  
(Choose more than stage if applicable)

- a) Collecting the needed information
- b) Determining the Temporary Facilities
- c) Determining the Temporary Facilities Size
- d) Determining the Temporary Facilities Location
- e) Other (specify) .....

11) Do you think that the site layout plan must be updated with the project's duration?

a) Yes                      b) No    why: .....

12) Do you think that the site layout plan could affect the:

- a) Project cost/time                      (Yes / No)    if Yes, specify the percentage .....%
- b) Project safety operation              (Yes / No)    if Yes, specify the percentage .....%
- c) Surrounding environment              (Yes / No)    if Yes, specify the percentage .....%

13) Did you face any problem which resulted from an inadequate site layout planning?

a) Yes                      b) No

*If No, Please **Skip** the next three questions and go to question (17)*

14) What are these problems?

.....  
.....  
.....

15) How did you solve these problems?

.....  
.....  
.....

16) What are the impacts of these problems on the project?

.....  
.....  
.....

17) Did you *use* or *hear about* an automated system which is capable of executing the site layout planning task?

a) Yes                      b) No

**18) Do you support such automated systems?**

a) Yes                      b) No

why: .....

**19) If there is a new automated system that will be developed, what do you think it should include?**

.....  
 .....  
 .....

**20) Could you please choose the most 14 repetitive temporary facilities in construction sites from the following table, and give an approximate size for each of them as well.**

***Note:** there is more available space if you need to add more temporary facilities.*

No.	Temporary facility	Mark	Size (m)
			(width*length*height) (Height: if it was closed area)
1	Project manager office		
2	Project staff/engineer office		
3	Subcontractor office		
4	Project staff/engineer toilet		
5	Labor dining and resting room		
6	Labor bathrooms		
7	Security office		
8	Information and time keeper office		
9	First aid office		
10	Site main gates (entries and exits)		
11	Tower crane		
12	Concrete batch plant		
13	Cement storage area		
14	Sand and aggregate storage area		
15	Rebar storage and fabrication area		
16	Timber storage area		
17	Scaffold storage area		



18	Construction materials storage area		
19	Formwork storage area		
20	Finishing materials storage area		
21	Electrical storage area		
22	Sanitary storage area		
23	Equipment storage area		
24	Hazard materials storage area		
25	Construction equipment parking area		
26	Car parking area		
27	Welding shop		
28	Carpentry shop		
29	Maintenance workshop		
30	Sampling/ testing lab		
31	Water tank		
32	Other (specify)		
33	Other (specify)		
34	Other (specify)		

**21) Now could you please help in specifying the interrelation closeness weight between the previously chosen temporary facilities themselves and the proposed building? The interrelation closeness weight reflects the closeness or distance between any pairs of facilities and will be based on:**

***1-Travel cost/time between the facilities inside the construction site***

Here six governing factors will be utilized to set the interrelation closeness weight between any pairs of facilities for the travel cost/time. The six governing factors are:

1. Equipment work flow (EF): transportation and movement of equipment on site and so forth from one facility to another.
2. Material work flow (MF): transportation and movement of materials on site and so forth from one facility to another.
3. Personnel flow (PF): movement of engineer, staff and labours on site and so forth from one facility to another.
4. Information flow (IF): communication and distribution of information on site and so forth from one facility to another.

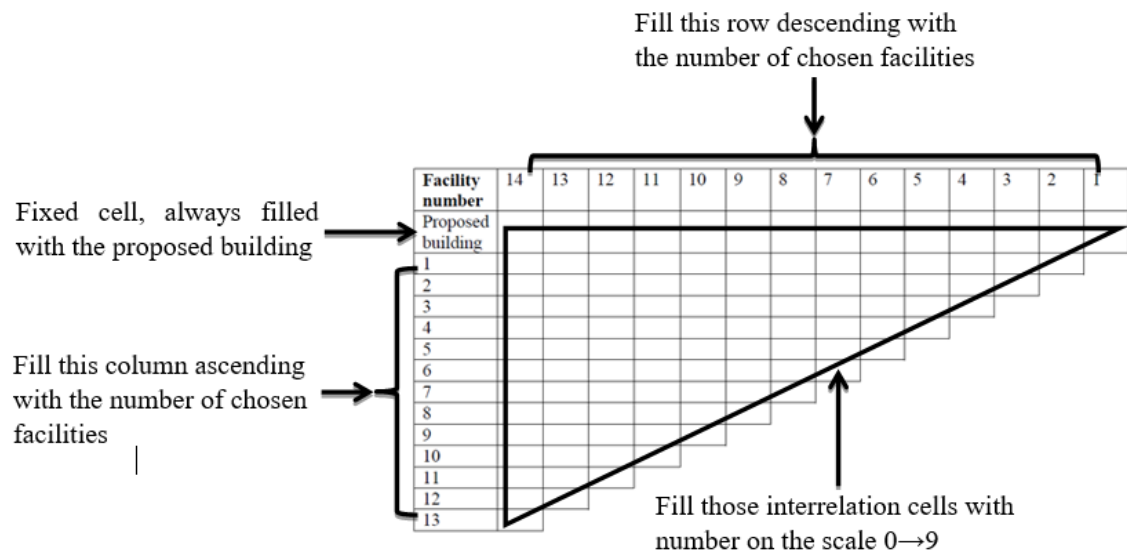
5. Time preference (TP): time factors to locate any two facilities close or far from each other.
6. User preference (UP): user desire to locate any two facilities close or far from each other.

To identify the interrelation closeness weight, there will be six relation matrices that express the six governing factors (mentioned before). You have to fill the facility number from the chosen 14 facilities above in (Question 20), and then fill the relations between them with a 9-point scale. The 9-point scale starts from 0 to 9, but you should know that:

Zero means that the relationship between these two facilities according to governing factors is undesirable or there is no relation between them.

Nine means that the relationship between two facilities according to governing factors is as close as possible.

**Example matrix** (Factor governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the factor governor.



**Relation matrix 1** (Equipment work flow governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the equipment work flow.

[illegible]

**Relation matrix 2** (Material work flow governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the material work flow.

[illegible]

**Relation matrix 3** (Personnel flow governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the personnel flow.

[illegible]

**Relation matrix 4** (Information flow governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the information flow.

[illegible]

**Relation matrix 5** (Time preference governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the time preference.

[illegible]

**Relation matrix 6** (User preference governor): choose a number on the scale 0→9, this number reflects the degree of relationship according to the user preference.

[illegible]

## 2- Safety consideration between the facilities inside the construction site

The interrelation closeness weight here reflects the degree of relationship between facilities according to safety consideration in construction site with a 9-point scale. The 9-point scale start from 0 to 9 but you should know that:

Zero means that the relationship between these two facilities according to safety consideration is undesirable or dangerous to be close to each other.

Nine means that the relationship between two facilities according to safety consideration is normal/ applicable to be close to each other.

**Safety relation matrix** (Safety governor):

[illegible]

**Thank you so much for your participation and your precious time.**

## APPENDIX B: RESPONDENTS EXAMPLE

**Task 1:** *Open the ASLS through MATLAB software.*

Open the MATLAB program from the computer desktop, write (ASLS) in MATLAB command windows then press enter.

**Task 2:** *Input data for a new project.*

Press the NEW button and input the following project (Example project) with all its data (as shown in the next table) as required in the ASLS windows, then press SAVE button.

**Project Name:** Example project.

**Company Name:** Elzahraa.

**Project Location:** Borj Elarab.

**Project Description:** Private villa.

**Prepared By:** User.

**Study Date:** the test date.

**Project Start Date:** 1<sup>st</sup> of March 2015.

**Project Duration:** 153 Days.

**Project site boundary:** width = 68 m / length = 61 m.

Table: Example project facilities data.

No.	Facility Name	Facility ID	Facility Type	Facility start date	Facility duration (in days)	Size (W*L) in meters	Facility Location	
							X	Y
1	Guard office	GF	Fixed	1/3/2015	153	2*2	65	9
2	Project Office	PO	Static	1/3/2015	153	4*6		
3	Mixing area	MA	Static	20/3/2015	100	6*6		
4	Steel area	SA	Static	10/3/2015	90	12*12		
5	Wood area	WA	Static	5/3/2015	140	12*6		
6	Materials store	MS	Static	3/3/2015	150	10*6		
7	Proposed villa	PV	Fixed	1/3/2015	153	36*20	30	41
8	Gate	GA	Fixed	1/3/2015	153	6	68	3

\*consider all facilities are 0 in height and orientation.

**Task 3: Open and edit an old project.**

Press the OPEN button and choose project called Example project 1 and edit the following data, then press SAVE button.

For the project information (prepared by) change the name to your name.

For the fixed facility proposed building 1 change its name to proposed villa 1.

For the fixed facility guard office change its ID to GF.

For the static facility proposed office change its duration to 153 days.

For the static facility materials store change its start date to 3/3/2015.

**Task 4: Transfer data between two different projects.**

While you open the example project 1, press the Obstacles button and export the tree obstacles to the ASLS main library, then press SAVE button. Reopen the project you



enter in task 2 (example project) and import the tree obstacles to it, then press the SAVE button.

***Task 5: Run the ASLS.***

Save all data you enter in task 3 for the Example project then Press the RUN button.